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ABSTRACT

Studies investigating the functioning of persons who have cerebral lesions and evidence from the study of commisurotomized and normal subjects are reviewed. A study of recognition of pictorial stimuli by right-handed male children is also discussed. Studies about cerebral lesions and associated deficits have yielded information about the perceptual and cognitive abilities subserved by the left and right hemispheres of the brain. Two lines of inquiry concern: the study of patients who have undergone transection of the corpus callosum and observations of functional asymmetries resulting from dichotic and lateralized tachistoscopic presentation of stimuli to normal subjects. In a pictorial recognition study, 18 right-handed first, second, and third grade boys were tested. The subjects had no familial history of left-handedness. The study results clearly support the hypothesis that between the ages of five and seven a change takes place in the relative efficiency of the hemispheres for the recognition of pictorial stimuli. It is suggested that these behavioral transitions reflect a change in the relative efficiency of the hemispheres for information processing. It seems probable that in this age period previously less efficient left hemispheric verbal processes come to surpass right hemispheric processes that have an initial superiority. (SW)

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THE DEVELOPMENT OF FUNCTIONAL PERCEPTUAL ASYMMETRIES IN THE CEREBRAL HEMISPHERES OF MAN [1]

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It has long been know that the human brain is functionally asymmetrical with different patterns of dysfunction resulting from damage to the left or right hemispheres. Analysis of the deficits resulting from lateralized cerebral lesions is the oldest method of studying this asymmetry, and such analysis has yielded a great deal of information about the perceptual and cognitive abilities subserved by each hemisphere. Such information has been supplemented in recent years by data from two new lines of inquiry: (1) the study of patients who have undergone transection of the corpus collosum and (2) observations on functional asymmetries resulting from dichotic and lateralized tachistoscopic presentation of stimuli to normal subjects. Evidence from the study of lateralized lesions will be reviewed first, followed by relevant findings from the study of commisurotomized and normal subjects.

Brenda Milner (1971, 1974) has reviewed the unilateral lesion data and concluded that in adult right-handed subjects the typical pattern is a left-dominance for language and a right-dominance for many still rather ill-defined non-verbal processes, including aspects of spatial and music perception. She noted however that homologous areas in the two hemispheres play a somewhat similar behavioral role, with the left frontal and left temporal lobes sharing in the overriding verbal functions of that hemispere, while the right frontal and temporal lobes subserve the non-verbal specializations of the right hemisphere.

The dominance of the left hemisphere for speech in right-handed subjects has been well-known since the nineteenth-century observations of workers such as Broca. Until recent years it was assumed that the left hemisphere was also dominant for all higher cognitive functions, since no dramatic and immediately obvious deficits resulted from damage to, or even complete removal of, the right hemisphere. In more recent years, the functions for which the right hemisphere is prepotent have begun to emerge.

Removal of the left-temporal lobe generally results in a selective impairment for the learning and memory of verbal materials (Blakemore & Falconer, 1967). Right-temporal lobectomy, on the other hand, impairs the recognition and recall of stimuli that are not easily verbally coded, such as nonsense patterns and melodies (Kimura, 1963; Milner, 1968). The learning of stylus mazes, both visual and tactile, is also disturbed by right-temporal damage (Corkin, 1965; Milner, 1965). Meier and French (1965) described the loss after right-temporal lobectomy as a deficit in complex forms of visually guided behavior. Visually guided behavior necessarily involves orientation in space, and it has been suggested (Butters, Soeldner, & Fedio, 1972) that there are two spaces involved: a personal space mediated by the frontal lobes, and an extrapersonal space

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mediated by the parietal lobes. Although the left hemisphere does seem to share in spatial tasks to some degree (Ratcliff & Newcombe, 1973), Whitty and Newcombe (1965) have characterized the right hemisphere as dominant for visual-spatial orientation and consequent manipulation of objects and the body in extrapersonal space.

In recent years, a number of patients have undergone midline cerebral commisurotomy for the relief of epilepsy. In such patients, the two hemispheres function independently and can thus be individually tested to reveal their differential competencies. Study of commissurotomized subjects has substantiated and extended the knowledge garnered by analysis of brain-damaged subjects. As expected, the left hemisphere has been found to be dominant for speech, writing, and calculation (Sperry, 1974). The right hemisphere has been found to be dominant for pattern recognition, both tactile (Milner & Taylor, 1972) and visual (Nebes, 1973); and to be better at spatial transformations of sensory input, i.e., construction of a whole from fragmentary information (Nebes, 1974). Matching of a pattern with missing parts, presented in free vision, with answers presented tactually also showed a right hemisphere superiority, although the left hemisphere could also do the task (Cahlia & Sperry, 1973).

Testing of commisurotomized subjects has revealed a right hemisphere capacity for language which was previously undetected. Gazzaniga (1970) found that split-brain subjects were able to read letters, numbers, and short words flashed in the left visual field (and therefore projected to the right hemisphere), and to pick the appropriate stimuli out of a group. The right hemisphere could also tactually retrieve objects (with the left hand) which were verbally described in an abstract manner (Nebes, 1974). For example, when the subject was told to find a round, thin object made of metal, he chose a coin. That this performance was not mediated by ipsilateral motor pathways from the left hemisphere is demonstrated by the fact that the subject was unable to name the object his left hand had picked out (without being able to see it), calling it a spoon. The right hemisphere was thus shown to comprehend not only single printed words, but also a series of words in a description of an object. Gazzaniga and Hillyard (1971) tested the right hemisphere's capacity to distinguish between active and passive voice, present and future tenses, and singular and plural, and found that it performed no better than chance with any of these distinctions. They concluded that the right hemisphere is incapable of recognizing the relationship between subject, object, and verb. The capacity of the right hemisphere to comprehend language is complicated by the finding that verbs flashed in the left visual field were apparently not comprehended (Gazzaniga, Bogen, and Sperry, 1967). The split-brain subjects were unable to perform simple actions (smile, wave, etc.) flashed in print in the left visual field. They could however perform the action if a picture of the desired action was flashed. Levy (1970), arguing that the initiation of an action by the right hemisphere could be noticed and blocked by the left, flashed verbs in the visual field, but utilized three different performance measures: (1) performing the action, (2) pointing to a picture of the act, and (3) tactually (without visual guidance) retrieving an object associated

with the action (e.g., a toy chair for "sit"). She confirmed the inability of the right hemisphere to act out the verb and found only chance performance with the picture pointing task. The subjects were very successful in picking the appropriate object however. Levy attributed this finding to the fact that it would be more difficult for the left hemisphere to interfere with an action whose consequences were unknown to it (the selection of an object with the left hand) than it would for it to interfere with an easily observed action.

Levy's conclusion that the inability of the right hemisphere to carry out an action was a result of left hemispheric interference was supported by an experiment by Gordon (1973). Utilizing split-brain subjects and a dichotic listening technique, Gordon found that when two commands were given, one to the left and one to the right ear, the left hand carried out the right ear task and the right hand carried out the left ear task. Since the subject was unable to verbalize the left hand task it was concluded that the right hemisphere had carried out the task unobstructed by the left hemisphere with was occupied by its own task.

A major problem for the interference hypothesis is that, as noted, the right hemisphere was able to carry out pictured actions without left-hemispheric interference. There would seem to be no reasonable explanation of how the left hemisphere could differentiate between actions initiated by words and actions initiated by pictures, both flashed exclusively to the right hemisphere, and interfere selectively with the verbally initiated actions. A further complicating factor is a finding reported recently utilizing lateralized tachistoscopic presentation of nouns and verbs to normal subjects (Caplan, Holmes & Marshall, 1974). Using three different classes of words, they found that nouns derived from verbs (e.g., helper) as well as words capable of use as either a noun or a verb (e.g., father) were recognized better than simple nouns (e.g., river) when presented in the left visual field. Such findings preclude, at present, any clear-cut formulation of right-hemispheric language comprehension. The data relating to the expressive language capacities of the right hemisphere are also not as clear-cut as might be hoped.

An early report of right-hemispheric speech capacity (Butler & Norrsell, 1968) was complicated by the long (up to twenty second) stimulus exposure periods utilized. Even with proper control of eye movement, such long periods allow the hemispheres to engage in cross-cueing. Gazzaniga and Hillyard (1971) found such cross-cueing to be taking place in a split-brain subject who could give a verbal report of a number flashed in the left visual field. The subject reported that he would count silently (with his left hemisphere) until he came to a number which "stuck out." Teng and Sperry (1973), however, reported evidence of a right hemispheric ability to verbalize digits and letters when flashed at 100 milliseconds with immediate report, which probably precludes cross-cueing. Levy (1969) has also found evidence of a possible right-hemispheric capacity for expressive speech, suggesting that this capacity is normally unobservable because of competition from the left hemisphere for control of the articulatory apparatus. Such a view is supported by

the finding that several split-brain subjects could spell words upon blindly feeling the letters with their left hand and upon blindly feeling words, could then often write them using the left hand, without being able to verbalize the word being written (Levy, Nebes & Sperry, 1970). The greater success of the right hemisphere in writing as compared to speaking could possibly result from the strong contralateral control of the left hand by the right hemisphere, allowing resistance to left-hemispheric interference. The articulatory mechanism, on the other hand, is strongly controlled by the left hemisphere, and it is therefore probably extremely difficult for the right hemisphere to take control and issue a word.

Levy (1974) has suggested that the right and left hemispheres recognize speech in different manners, the left analyzing each successive phoneme in a linear manner (perhaps by comparison with the appropriate articulatory model [Liberman, 1974]), the right treating each word as an auditory gestalt. The right hemisphere, in this view, is capable of semantic but not phonetic decoding of the speech signal. Thus, while the right hemisphere could be capable of recognizing that two words meant the same thing, it would nevertheless not be able to tell if they rhymed. The right hemisphere would decode spoken and written input by having integrated graphologies and phonologies linked in an associative manner with their appropriate meanings. While the right hemisphere could comprehend language, it would be incapable of breaking speech down into the phonetic components necessary for its articulation. Studdert-Kennedy (1975), in reviewing dichotic studies with normal subjects, reached a similar conclusion and noted that activation of the language hemisphere by speech seems to entail analysis of the speech signal into its phonetic components.

The dichotic technique (simultaneous and different input to each ear) allows the exploration of lateral asymmetries using normal subjects, thus eliminating the possibility of complicating brain dysfunctions. The original finding that the dichotic technique could be used to detect differences between the ears which correlated highly with speech lateralization as determined by the Wada technique (Wada, 1949; cited in Milner, 1974) was made by Kimura (1961).[2] She found that the typical pattern of a left hemispheric specialization for speech correlated with a right ear advantage for verbal stimuli and that subjects who demonstrated a right hemispheric specialization for speech showed a converse ear superiority. Knox and Kimura (1970) later found an ear advantage for non-verbal stimuli (music) that was the opposite of that for speech.

Kimura's interpretation of these findings depends upon two points: (1) the differential specialization of the hemispheres for the perception of speech and non-verbal stimuli and (2) stronger contralateral than ipsilateral ear-to-hemisphere connections and a concommitant suppression of ipsilateral input during the processing of contralateral input. The first point has been well established. The second point was recently strongly supported by Zaidel (1973, 1974) who found that split-brain subjects showed nearly total left ear suppression of dichotically presented verbal

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[2]The Wada technique involves injection of sodium amytal into the carotid artery of one side which produces a contralateral paralysss, anesthesia, and blindness. If the injection is made on the side of the hemisphere dominant for speech the patient is totally unable to speak for several minutes and then makes many speech errors including mistakes in repeating well known series (e.g., the days of the week). When the injection is made on the side nondominant for speech a transient speech disorder occurs which rarely lasts longer than a few seconds (Milner, 1974).

material although they performed equally well with the left and right ears during monaural presentation. Darwin (1974) delineates two variables which contribute to the occlusion of ipsilateral pathways. The first is the duration of the sound, with shorter sounds causing greater occlusion than longer sounds. The second is the similarity between the sounds, with increasing similarity causing greater occlusion of the ipsilateral pathway.

A number of studies have attempted to uncover the variable which determines which hemisphere will be superior for a particular class of stimuli. Shankweiler and Studdert-Kennedy (1967) found that a right ear advantage (REA) could be elicited by consonant-vowel-consonant trigrams differing only in the initial stop consonant. No differences were found for nonsense syllables differing only in the vowel. A possible explanation of this difference is that since vowels are of longer duration than consonants they cause less occlusion of the ipsilateral pathway (Darwin, 1974). Considerable research (see Liberman, 1974) has demonstrated that isolated consonant-vowel pairs are the smallest units capable of eliciting an REA. If speech is chopped into smaller pieces (e.g., second formant transitions), no REA results. Studdert-Kennedy (1975) has claimed that the advantage of the speech hemisphere is due to its possession of a "linguistic device" which analyzes the speech signal into its segmental phonetic components. While both hemispheres can analyze the auditory parameters of the speech signal, only the hemisphere dominant for speech can extract the linguistic features from those parameters.

Darwin (1969) presented subjects with four pitch contours which were carried on a number of different timbres, one of which was the word "tea." The word condition yielded a left ear advantage (LEA) as large as the other conditions in which the pitch contours were carried on a non-speech sound. Bartholomeus (1974), using sung speech as stimuli, found a change in ear superiority depending upon whether the subject attempted to identify the melody or the sung letter sequence. Since the same stimuli yielded in one condition an LEA and in the other an REA, the variable causing the ear differences must have been the level of processing required by the task. Even when the stimuli presented to the ears is verbal, the left hemisphere will not show an advantage unless linguistic analysis of the signal is required by the task.

The stimuli for which the right hemisphere shows an advantage are not as easily characterized as those showing a left hemisphere advantage. Left ear advantages have been found for melodies (Cook, 1973; Kimura, 1964; but see also Robinson & Solomon, 1974), intonation contours from filtered speech (Blumstein & Cooper, 1974), emotional stimuli (Corman & Nachson, 1973), and environmental sounds (Curry, 1967; Knox & Kimura, 1970). Papcun, Krashen, Terbreek, Remington and Harshman (1974) presented Morse code dichotically to Morse code operators and naive subjects. The operators showed an REA while the naive subjects showed an REA only if fewer than seven elements were presented: for stimuli with more than seven elements there was an LEA. Papcun et al. suggested that the longer string required wholistic processing in naive subjects and thus showed a right hemisphere advantage, while the shorter string allowed subpart or sequential processing.

The suggestion that the left hemisphere processes information sequentially, the right hemisphere wholistically, was also made by Cohen (1973). Utilizing a split visual field technique, he found an increase in reaction time (RT) with each letter added to a set judged by a subject to be all identical or different only in the right visual field (RVF). In the left visual field (LVF) there was no increase in RT with additional letters. This suggests wholistic processing by the right hemisphere (since there was no increase in RT with additional letters) and sequential processing by the left hemisphere (since each additional letter caused an increase in RT).

The split visual field technique depends upon the fact that the visual system is arranged such that if a subject is fixating a point in space, everything to the left of that point (LVF) will be initially projected to the right hemisphere and everything to the right (RVF) will be projected to the left hemisphere. Gazzaniga (1970, p. 90) using split-brain subjects, demonstrated that the visual field is split crisply down the midline with little or no overlap between the left and right visual fields. Care must be taken to ensure that the stimuli are presented fast enough to preclude eye movements, which have a latency of about 200 milliseconds (Neisser, 1967, p. 17). Reaction time measures must be used since there is a rapid spread of information between the hemispheres in a normal intact subject.

Using a split visual field technique, Miskin and Forgays (1952) found a RVF advantage for the recognition of single English words, and a LVF advantage for Yiddish words. Heron (1957) attributed this, and his own finding of an advantage for letters on the left of a string presented across the fixation point, to the normal left to right scan of English reading subjects and the opposite scan of Yiddish subjects. Bryden (1960) substantiated this interpretation by demonstrating that with non-alphabetic stimuli the visual field advantage would switch depending upon whether the subject reported the array from left to right or from right to left. The importance of a post-exposural visual scan in the visual field effect has been clearly demonstrated, and White (1973) has argued that it is an important component in lateral asymmetries. A number of studies have controlled for scan, however (e.g., by using vertical arrangements of letters), and have still found a RVF superiority for letters, words, and digits (Barton, Goodglass & Shai, 1965; Bryden, 1966). Thus, although a scan mechanism should always be controlled for, an explanation of the RVF advantage for verbal materials based on a left-hemispheric superiority for the processing of linguistic material seems to be demanded by the data.

The RVF superiority for verbal stimuli is paralleled by a LVF superiority for facial recognition (Gilbert & Bakan, 1973), depth perception (Durnford & Kimura, 1971), recognition of complex fors (Fontenot, 1973), and the direction of lines (Fontenot & Benton, 1972; see Berlucchi, 1974 for discussion of a contrary result reported by White, 1971). Bryden and Allard (1976) have demonstrated a LVF superiority for the recognition of script-like letters: the usual RVF advantage was found for block letters. They suggest that the right hemisphere is more efficient than the left at global preprocessing operations.

The results from studies utilizing a split visual field technique substantiate the results obtained using a dichotic technique and also parallel the findings from the study of split-brain and unilaterally brain damaged subjects. The fact that the two hemispheres possess differential capacities for the processing of verbal and non-verbal stimuli has been clearly demonstrated and is not seriously disputed. The mode of processing utilized by each hemisphere has been characterized by different authors as processing information in an analytic, rational, propositional, abstract, linear, discreet, and/or categorical manner, or simply as being specialized to deal with phonological and syntactic information. The right hemisphere on the other hand has been called a synthetic, intuitive, appositional, concrete, parallel, diffuse, and/or acategorical processor that perceives information as a meaningful gestalt (see Bogen, 1969 for a historical review of characterizations of the hemispheres).

As can be seen there is general agreement on the broad parameters of differential hemispheric processing, with differences being mainly in emphasis. White (1972) rather broadly characterizes the right hemisphere as specialized for the analysis of stimulus information, and the left as better at output-response functions. The group at Haskins Laboratory tend to view hemispheric specialization somewhat more narrowly, seeing it as resulting from the left hemisphere's unique ability to do grammatical recoding (Liberman, 1974) or segmental phonological analysis (Studdert-Kennedy, 1975). Their emphasis is upon the left hemisphere's capacity to analyze the speech signal which is in turn dependent upon its ability to articulate.

Semmes (1968) has suggested that the processing difference between the hemispheres may result from a basic underlying difference in neural organization. Studying 124 war veterans with penetrating brain wounds, she found a difference between the hemispheres in the relationship of lesion site and deficits on tests of cutaneous sensitivity. Left hemispheric lesions causing deficits were highly localized in the sensori-motor cortex of the parietal lobe whereas lesions in the right hemisphere causing deficits were not so focally located. Sutdy of pathological reflexes of the fingers yielded similar results. Semmes concluded that the left hemisphere is focally organized while the right hemisphere has a more diffuse organization. Thus a relatively small lesion at the same site in the right hemisphere would impair several functions slightly but none severely.

Semmes suggests that the left hemispheric specialization for language stems from this basic difference in sensori-motor organization. Noting that speech requires extremely complex control of the articulatory mechanism, she suggests that the convergence of one level of similar focally organized units upon the next level might bring about a more finely modulated control of output. She states that "the development of such precise control of the articulatory mechanism may provide an optimal substrate for speech representation in the left hemisphere")p. 22). Similarly, the diffuse neural organization of the right hemisphere might optimally subserve the synthetic, parallel processing of stimuli into a gestalt.

Broadbent (1974) suggests that integrated action requires both a stable representation of the environment and accurate categorization of changes which occur in that environment. He speculates that the categorization of changes may be dependent upon left hemispheric processes, whereas the stable representation of the environment may be dependent upon right hemispheric processes. Categorization may be viewed as a process by which a more or less diverse set of stimuli come to elicit the same response. How a stimulus is recognized as belonging to a particular response category, whether through its possession of a set of criterial features or through its resemblance to a prototypical category member, is currently debated in the literature (see Rosch, 1975; Homa & Chambliss, 1975), and is beyond the scope of this paper. The use of an articulatory motor behavior (a word) as the defining response of a category however can greatly facilitate the cognitive manipulation of the set of stimuli labeled by the word. The particular motor response that produces a word can be used symbolically to stand for whole sets of stimuli. This motor response can be more easily ordered in relationship to other categories of stimuli (also represented by verbal motor responses) than could the sets of stimuli themselves. The fact that motor behavior is by its nature sequentially ordered in time (Lashley, 1951) dictates that thought processes using articulatory motor responses (or just their central representations) must also be sequentially ordered in time.

The articulatory musculature is somewhat unique in that it is a unitary rather than a bilaterally duplicated system. Levy (1969) notes that this being the case, it is probably well that control of the articulatory mechanism is unilateral since competition between the two hemispheres for the control of a unitary output mechanism could be counterproductive. If the left hemisphere is, as suggested by Semmes, better organized than the right for the control of fine motor movements, then the left hemisphere's superiority for verbal processes as well as the linear and sequential mode of processing characteristic of the left hemisphere may both be seen to result from this differential organization. In this view the left hemisphere would not necessarily be superior to the right in categorization, but rather in the manipulation of categories. The diffuse organization of the right hemisphere could underlie its superiority for the organization of incoming stimuli (posited by White, 1972) and this stimulus information could be used to build the stable representation of the environment that that Broadbent (1974) suggests is lateralized to the right hemisphere.

A number of recent studies have demonstrated the importance of spatial representation and localization. Wallace (1971) found that reaction time to shapes in the left or right visual fields was faster when the response was made to the side that was stimulated, regardless of which hand was used. Richard, Craft, and Webster (1973) and Callan, Klisz, and Parsons (1974) have replicated Wallace's results using auditory stimuli. They found faster key presses with a key on the right when the stimulus was on the right and faster presses with the left key for stimuli on the left regardless of whether the hands were crossed or uncrossed.

Goldstein and Lackner (1974) found that laterality effect could be influenced by a subject's perceived spatial orientation. Subjects who

wore prisms that displace visual space to the left showed a reduced right ear advantage for verbal stimuli. The right ear advantage was increased by prisms displacing visual space to the right. Morais and Bertleson (1973) found that while subjects showed a right-speaker advantage for verbal stimuli presented over left and right loudspeakers, they show a significant front speaker advantage if the stimuli are presented over front and left or front and right speakers. These studies emphasize the importance of localization processes and suggest that the hemisphere to which a stimuli is routed is determined at least partially by the perceived spatial origin of the stimuli. It is interesting to note that cells have been found in the parastriate cortex of animals which respond to both visual and auditory stimuli, but only if the sound source is located in the neuron's receptive field for visual stimuli (Morrell, 1972).

Kinsbroune (1970) has proposed that lateral asymmetries arise from an attentional enhancement of the side of space contralateral to whichever hemisphere is actively engaged in information processing. Since the left hemisphere subserves the right side of space, for example, verbal information processing in the left hemisphere would bias attention to the right, giving faster reaction times to visual stimuli in the RVF or to auditory stimuli in the right ear. Kinsbourne (1970), utilizing a visual task which initially showed no field differences, neatly supported this hypothesis by demonstrating that a RVF advantage resulted from having the subject covertly rehearse six words. A LVF advantage for the previously neutral task resulted from the rehearsal of a melody. Kimurs and Durnford (1974) have reported a study which supports Kinsbourne's hypothesis. They found that subjects showed a RVF advantage for the recognition of geometric stimuli if they had just completed a letter recognition task (activiting the left hemisphere) but no field advantage if the geometric task was done first. There have also been numerous reports of lateral eye movements to the right when people consider verbal problems and eye movements to the left when they consider spatial problems (Bakan, 1969; Day, 1964; Gur, Gur, & Harris, 1975). Such eye movements have been interpreted by Kinsbourne as resulting from activation of the hemisphere contralateral to the direction of movement.

Kinsbourn'e hypothesis was not supported in a recent study designed specifically to test it (Berlucchi, Brizzolara, Marzi, Rizzolatti, & Umilta, 1974). Kinsbourne (1970) stated that a crucial test of his hypothesis would be to present in a random manner stimuli which normally show a LVF advantage mixed with stimuli which normally show a RVF advantage. A marked decrease in field effects would be expected since the subject would not be engaged in exclusive left or right hemispheric processing with a resultant enhancement of the contralateral visual field. Berlucchi et al. performed this experiment and found the usual RVF advantage for letters and LVF advantage for faces. This finding is weakened by the failure of Berlucchi et al. to include a control condition in which only letters or only faces were presented in order to see if there might be a decrease in the field effect with mixed presentation. Nevertheless, Kinsbourne's hypothesis is weakened by the finding of significant differences between the visual fields in the recognition of letters and faces presented in a mixed and random manner. Kinsbourne's (1970) findings as

well as those Kimura and Durnford (1974), and the study previously mentioned by Bartholomeus (1974) which showed that ear advantages for the same stimuli changed depending upon the task requirements are all dramatic results which stand in need of explanation. Kinsbourne's hypothesis seems to be the only plausible theory which would account for such findings.

While the emphasis in this paper has been on differences between the hemispheres, it should be kept in mind that the interaction and cooperation between the hemispheres is extremely important. Broadbent (1974) has noted that it has thus far proved impossible to find tasks which can be performed simultaneously within the left and right hemispheres without mutual interference. It is highly likely therefore that integrated action involves processes within both hemispheres. Moscovitch (1975) suggested that patterns may emerge when the hemispheres interact such that some abilities which are present may emerge and be realized in behavior while others may be inhibited. Guyer and Friedman (1975) argued that cognitive processing systems may develop at different rates and semi-independently. If this is true, then the study of the differential capacities of the hemispheres as they develop in the child may throw considerable light upon the pattern of functional asymmetries found in the adult.

Evidence supporting the possibility that anatomical asymmetries underlie the functional asymmetries of the hemispheres comes from several sources. Geschwind and Levitsky (1968) found a left-right morphological asymmetry observable by the naked eye in the posterior region of the superior surface of the temporal lobe (planum temporale) which is part of the classical area of Wernicke. In 65 % of the adult brains linear measurement was greater on the left side. Witelson and Pollie (1973), investigating the same region, found approximately 70 % of adult brains larger on the left in both area and linear measurement. More interestingly, they found a left-right difference in neonates proportionately as large as in the adult sample. The finding of greater cortical expanse in the temporal speech area of the left hemisphere in infants was replicated by Wada (cited in Milner, 1974). Wada found 90 % of both adult and infant brains larger in this area of the left hemisphere and reports that the asymmetry was visible at the gestational age of 20 weeks.

Molfese, Freeman, and Palermo (1975) recorded auditory evoked responses from the temporal region of infants, children, and adults in response to speech and non-speech stimuli. They found that in all three groups the left hemisphere auditory evoked responses to speech stimuli were larger than the right hemisphere responses. The asymmetry was reversed for non-speech stimuli (a piano chord and a burst of white noise). Differences between the hemispheres were found to decrease with age with both types of stimuli. A number of studies (Eimas, Siqueland, Jusczyk & Vigorite, 1971; Moffitt, 1971; Treub & Rabinovitch, 1972) have demonstrated that infants are able to preceive speech categorically. Like adults, infants seem to respond to speech sounds on the basis of their phoneme category rather than on the basis of changes within categories.

It seems likely that the anatomical asymmetries found in the temporal speech areas underlie a functional asymmetry of at least some aspects of linguistic ability. The categorical perception of speech sounds would seem to be a likely candidate for a linguistic ability based on anatomical asymmetries present at a very early age. It would be interesting to record auditory evoked responses from infants while presenting them with synthesized speech varying both between and within phonemic categories. If the categorical perception of speech stimuli is dependent upon processes " ired in" o the speech hemisphere, then it would be expected that only stimuli varying between phonemic categories would show the differences between the hemispheres characteristic of speech stimuli. Stimuli varying within the phonemic category would be expected either to show no difference between the hemispheres or to show the pat ern found by Molfese et al. to be characteristic of non-speech stimuli. Such a finding would offer conclusive proof that the left hemisphere is specialized for the perception of linguistic information from birth.

Indirect support for the possibility that some linguistic processes are lateralized at a very early age comes from studies of the development of handedness and cerebral dominance for speech. Gesell and Ames (1947) found that the tonic neck reflex position of infants was predictive of subsequent handedness in about 75 % of the cases observed. Seth (1973) studied the development of eye-hand coordination and handedness in infants 20 to 52 weeks old. A left hand preference in the youngest group gave way at about nine months to a right hand dominance. The right hand take-over appeared to occur on the basis of bilateral transfer rather than by practice and thus seemed to be a maturational rather than a learned change.

Annett (1970) recorded hand preference and manual skill in children three and one-half to fifteen years of age. Asymmetries in manual skill were found to be normally distributed, stable during growth and slightly greater in females than in males. She concluded that asymmetries of manual preference result from asymmetries of neuromuscular coordination which has an early and enduring role in manual control. Ingram (1975), working with children three to five years old, and Denckla (1974), working with children five to eleven, both found hand preference strongly established in the youngest groups tested. Denckla found a pattern in right prefering children of initial establishment of right sided function followed by a rapid increase in left sided function so that by age eight, there is only a very small right side superiority.

These studies indicate that an asymmetry in hand preference and manual skill is developed at a very early age and if anything decreases with age. Such a finding is of interest since numerous studies have shown that a strong relationship exists between cerebral dominance for speech and handedness. Satz, Achenbach and Fennell (1967) found that superior dexterity of the right hand was associated with contralateral left-sided speech dominance, whereas left hand dexterity was not associated with a particular speech dominance pattern as measured by a dichotic listening technique. They found that self-report of left hand preference was an extremely unreliable estimate of actual manual performance, but that those "left-handers" who showed speech representation on

the right, generally showed superior manual skills with the left hand. Utilizing a tachistoscopic task, Bryden (1965) reported a similar finding of left-side verbal dominance being associated with right hand dominance and a much greater variability in speech laterality in left-handers. Milner (1974) and Annett (1975) have reviewed work relating cerebral dominance for speech and for handedness. They conclude that there is overwhelming clinical proof that the left hemisphere is dominant for speech in most right-handers of right-handed ancestry and that the pattern in left-handers is less consistent.

Shankweiler and Studdert-Kennedy (1975) present evidence to support the hypothesis that cerebral dominance for both manual praxis and for speech perception should be viewed as gradients. Asymmetries in both dexterity and speech perception (measured dichotically) were found to vary across individuals along a continuum, and these variations in speech and manual dexterity were found to be correlated with each other. Such a pattern suggests that both gradients derive from a similar source. Geschwind (1975), Kimura (in press), Semmes (1968), and Shankweiler and Studdert-Kennedy (1975) have all suggested that cerebral dominance for speech and handedness may both result from a lateral specialization for the control of rapid, sequentially organized, fine motor movements. Support for this hypothesis comes from a number of recent studies. Kinsbourne and Cook (1971) found a motor decrement on the right hand but not the left during concurrent speaking, indicating in-erference between speech and manual activity controlled by the same hemisphere. This effect has recently been replicated (Hicks, in press; Lomas & Kimura, in press). Kimura (1973) has shown that free hand movements which accompany speech are more frequent with the hand contralateral to the speech hemisphere than with the ipsilateral hand. Such findings have been taken as evidence that there is extensive neural overlap between the control of upper limb sequences and the control of the speech musculature (Kimura, in press). Kimura and Archibald (1974) have found that patients with left hemisphere damage were impaired in the ability to copy unfamiliar meaningless movement sequences of the hands, and that this impairment was correlated with the impairment in speech production. The fact that meaningless manual sequences were impaired to a degree highly correlated with the degree of speech impairment suggests that the left hemispheric dominance for speech is based on its superiority for the control of sequential motor activity rather than on a superiority for meaningful or symbolic activity.

The evidence supporting a common process underlying cerebral dominance for speech and handedness when taken together with the evidence demonstrating a very early age of establishment of hand dominance strongly suggests that cerebral dominance for speech may lateralize at an early age also. Numerous studies utilizing a dichotic listening technique have substantiated this argument. A REA for verbal material, indicating a left hemispheric superiority for speech perception, has been found in children as young as three years of age (Ingram, 1975). Satz, Bakker, Teunissen, Goebel, and Van der Vlugt (1975) have reviewed a number of developmental studies which utilized a dichotic technique. All but one of the studies reviewed found a REA already established at the earliest ages tested and found no increase in the REA with age. The study which

did show an ear increase with age (Bryden, 1973) found a trend in the developmental magnitude of the ear assymmetry by age 10 which was not significant until ages 12 and 14. An earlier study by the same author (Bryden, 1970) had found that the percentage of right ear dominant subjects increased with age in right-handers but decreased in left-handers.

Satz et al. (1975) argued that the findings of an early age of establishment of a REA for speech stimuli are inconsistent with clinical data (see below). Pointing to methodological difficulties in previous dichotic studies (notably a ceiling effect), they conducted a study designed to control for procedural artifacts. They also used a multivariate method of analysis to provide a better assessment of the ear asymmetry. They found a trend for a right ear superiority as early as five or six but no significant differences between the ears until age nine. The developmental functions for each ear were curvilinear with positive slopes (indicating an increase in recall from both ears up to age nine) and negative acceleration (indicating that the rate at which gains were made grew smaller from year to year). The right ear functions were found to develop significantly faster than the left.

Satz et al. conceded that the weight of evidence favors an early age of onset of ear asymmetry. They postulated that by age five there is a bilateral but unequal representation of language which results in at least a trend towards a REA. This was not to imply however that complete left hemispheric language dominance is established by this age. They interpret both their own and Bryden's (1973) results as supporting an increase in degree of hemispheric speech lateralization with age. They concluded that regardless of the age of onset of lateralization, major changes in the magnitude of the ear asymmetry do take place after the age of five. The findings of studies which showed no increase after five were interpreted as resulting from procedural artifacts.

Berlin, Huges, Lowe-Bell, and Berlin (1973) reported a typical finding of a significant REA for consonant-vowel pairs at age five and no increase in REA with age. Noting that language skills do improve between five and thirteen years of age but that the REA does not, they concluded that the REA as measured by dichotic listening to nonsense consonant vowels is not an index of total language performance. Porter and Berlin (1975) discussed the Satz et al. study and suggested that it might not be necessary to dismiss the findings of no increase in REA with age as resulting from procedural artifacts. They postulated that different dichotic tests may tap different levels of language processing. The levels of processing tapped by different dichotic tasks may be lateralized to a different degree or may develop at a different rate. The Satz et al. study, for example, presented four digit pairs per trial and may have tapped slowly developing memory processes whereas studies using only one digit or nonsense word pair per trial might tap earlier maturing phonetic and auditory processes.

The interpretation of dichotic findings offered by Porter and Berlin seems very reasonable and it accounts for most but not all of the discrepancies reported in the literature. All but one of the studies reviewed by

Satz et al. conclude that sex is not a factor in the development of ear asymmetries. The Bryden (1973) study and an earlier study by the same author (Bryden, 1970), however, did find a significant sex difference, indicating an earlier age of establishment of language dominance in girls than in boys. Kimura (1963) found that boys lagged behind girls in the development of speech perception although both boys and girls had lateralized by age four. Pizzamiglio and McChini (1971) reported finding a greater degree of lateralization in girls at all ages tested (five through ten). Ingram (1975) as well as Geffner and Dorman (1976) report the rather anomolous finding that of all ages tested only four-year-old girls showed no REA for speech stimuli. Lake and Bryden (1976) found a greater REA in males than in females and speculated that even though males start out less lateralized, they eventually lateralize more thoroughly and completely than females.

Given these discrepant findings the only conclusion that it is possible to draw at present is that more study is needed to clarify the role of sex differences in the development of speech lateralization. A similar caution must apply to conclusions about the effect of socio-economic status on the development of the REA. A few studies (Kimura, 1963; Pizzamiglio & McChini, 1971) have found somewhat retarded development of lateralization in lower socio-economic classes, while others have shown no effect for socio-economic status or race (Dorman & Geffner, 1974; Geffner & dorman, 1976).

Only a few studies have investigated the development of hemispheric specialization using lateralized tachistoscopic techniques. Forgay (1953) found no visual field difference for word recognition in children from the second to the seventh grade. Olson (1973) presented three and four letter words either unilaterally or bilaterally to children in grades two through six. In marked contrast to Forgay's study, she found a RVF superiority at all ages which was as large as the RVF superiority for adults on a similar task (Orbock, 1952). Bilateral presentation was found to elicit a greater RVF superiority in the children than unilateral presentation (measured by percent correct in each field). In a further study reported in the same article, Olson (1973) reports finding a lack of a RVF superiority only in a small number of young (eight- and nine-year-old) delayed readers. Older delayed readers showed the usual RVF superiority.

Marcel, Katz, and Smith (1974) presented words unilaterally to the left and right visual fields of eight-year-olds. They found that reading proficiency tended to be correlated with the degree of left hemisphere superiority. Good readers showed greater RVF superiority for words than poor readers. Conversely, poor readers showed higher LVF scores than good readers. Marcel and Rajan (1975) replicated the finding of a RVF advantage for words in children seven to nine years old, and additionally found that recognition of faces was superior in the LVF, but this LVF superiority was not correlated with reading ability. A sex difference was also found. The male group showing greater RVF superiority for verbal stimuli also showed a greater LVF superiority for facial stimuli. The female group showing greater RVF verbal superiority showed a smaller LVF superiority for faces.

Buffery (1971) presented words dichotically to children five, six, and seven years old. The heard word then had to be matched with a tachistoscopically presented word. The condition in which the word was received dichotically in the right ear (left hemisphere), and visually in the LVF (right hemisphere) was found to be the easiest. The most difficult condition was when both the auditory and visual word were received by the right hemisphere. This pattern was significant in girls from five years onward, but in boys only from the age of seven. This finding is interesting in that it shows both a sex difference and a developmental trend in the development of lateral asymmetries, at least for boys. It is difficult to interpret however because of the mixture of dichotic and tachistoscopic techniques. There is compelling evidence that the asymmetries found with both dichotic and tachistoscopic techniques result at least in part from cerebral asymmetries in the processing of verbal and non-verbal stimuli. Nevertheless two studies (Bryden, 1965; Zurif & Bryden, 1969) failed to find any significant correlations between dichotic and visual half-field asymmetries.

Hines and Satz (1974), noted some methodological difficulties with the earlier studies and did find a significant cross-modal (i.e. visual and auditory) correlation in right-handers. In left-handers, there was no significant cross-modal correlation. Hines and Satz suggested that in left-handers there may be a disassociation of perceptual laterality effects in the auditory and visual modalities. If this is so, then the auditory and visual lateral asymmetries found in right-handers might also be subserved by separate processes which, though associated, might develop at different rates or be lateralized to a different extent.

Almost all of the data cited thus far point to an early age of lateralization of cerebral function in the human. The anatomical findings of a larger cortical expanse in the classical speech area of the left hemisphere in infants (Witelson & Pollie, 1963; Wada, 1974), the finding of a larger auditory evoked response to speech stimuli in the left hemisphere of infants (Molfese et al., 1975), and the finding that cerebral dominance for speech and handedness are closely related, and that handedness is established very early in life, all indicate that at last some components of language are are lateralized at a very early age. Dichotic studies have substantiated these findings, showing that a REA for speech stimuli exists at three years of age (Ingram, 1975) which has thus far been the youngest age testable by this technique. Tachistoscopic studies have been more equivocal, with an original study (Forgay, 1953) finding no visual field effects at all in children and a later study showing the adult pattern of a RVF advantage for verbal stimuli at the earliest age tested (Olson, 1973).

The suggestion that speech function is lateralized at an early age is, however, not supported by clinical observations of the effects on speech of unilateral brain damage. Basser (1962) reported clinical dat which indicates that injuries to the right hemisphere cause speech disturbance more often in children than in adults. Lenneberg (1967) interpreted such data as indicating that lateralization of language function is not complete until puberty. Hécaen (1976) has described a series of

26 cases of cortical lesions in children three and one-half to fifteen years of age. He noted the evidence supporting an early age of lateralization and the evidence of language disturbance after right-sided damage in children, and concluded that, although dominance is potentially fixed, it is susceptible to displacement up to a certain age. He also states that different language zones do not achieve their full maturation at the same time, allowing a reorganization of verbal function, even in the same hemisphere. Such a reorganization is, however, at the expense of other functions. Milner (1974) made a similar point. Brown and Jaffe (1975), noting differences in patterns of aphasia resulting at different ages from lesions at the same site, hypothesized that lateralization may continue throughout life with various functions becoming more localized both between and within the hemispheres.

The discrepancy between the clinical and the other data concerning the development of lateralization, as well as the sparsity of developmental tachistoscopic studies, and the contradictory findings of the few which have been performed, all demonstrate the need for further study. The present study was designed to investigate the development of hemispheric specialization utilizing a tachistoscopic technique. Pictorial stimuli were used in order to eliminate the effect of increasing practice with written verbal material in older children.

In adults, drawings of familiar objects are more accurately identified when presented in the RVF than in the LVF (Bryden & Rainey, 1963). This presumably results from the high verbal association value of such drawings. Visual field advantages have not been found for nonsense forms (Kimura, 1966) or random shapes of low-complexity (Fontenot, 1972; see also Fontenot, 1973). Fontenot (1972) and Dee and Fontenot, (1973) have however found a LVF advantage for high-complexity shapes of low verbal association value. In the present study drawings of common objects were used in order to assess the development of visual asymmetries. Because the verbal system in the child is still developing, the strength of the association between a drawing and its' name might be somewhat less than in an adult. Changes in the magnitude or direction of the RVF advantage for drawings of common objects found in adults might therefore be expected with increasing age.

A manipulation modelled after a study by Conrad (1971) was used in the hope of assessing verbal as well as non-verbal processes, Conrad found that children below the age of five did as well memorizing the positions of a group of pictures whose names rhymed (e.g., cat, hat, rat) as they did with a similar list whose names did not rhyme (e.g., cat, cow, spoon). Children above the mental age of five made increasingly more mistakes on the list of pictures whose names rhymed even though the task did not demand that the verbal labels be used. This would indicate that at about five years of age, the children begin to use the names of the pictures to memorize the list, and the phonetic similarity of the rhyming words began to cause confusions.

Levy (1974) has claimed that the right hemisphere is capable of semantic but not phonetic decoding of language and can thus not tell if two words rhyme, This being the case, confusions between pictures whose

names rhyme must result from left hemispheric processes. In the present study, therefore, it was hypothesized that pictures whose names rhymed would be confused causing an increased reaction when presented to the left hemisphere but not when presented to the right. It was hoped that this technique would allow the assessment of verbal processes utilizing non-verbal stimuli. An increase in reaction time to the pictures whose names rhymed, in comparison to pictures whose names did not rhyme, would indicate the use of a phonological code which Levy claims is an exclusively left-hemispheric ability. Specifically it was hypothesized that pictures whose names rhymed would show an increased reaction time in comparison to pictures whose names did not rhyme, but only in the left hemisphere. In the right hemisphere there should be no difference between pictures with rhyming and those with non-rhyming names since the right hemisphere would presumably be using a non-verbal or at least non-phonological code.

Conrad interpreted his findings as indicating a shift from a non-verbal to a verbal memory code at about the age of five. Numerous other studies have also emphasized the importance of the five to seven age span in the development of the child. White (1965 has reviewed the literature relating to this period and lists over 21 behavioral changes which occur between the ages of five to seven. The use of words as "second-order cues evoking behavior which the stimuli themselves would not call forth" (White, 1965; p. 210) is apparently a major component in many of the behavioral changes which occur at this time. If the growth of verbal abilities causes a major change in learning strategy and other behavior, as the Conrad study and the studies reviewed by White seem to indicate, then a change in efficiency of hemispheric processing might also be expected to occur around this time.

The behavioral changes in the five to seven period seem to reflect a change from non-verbal to verbal processes. It was hypothesized therefore that at about the age of five to seven a shift from a right hemisphere superiority to a left hemisphere superiority would occur, reflected in faster reaction times to visual stimuli in the LVF in younger children and faster reaction times to visual stimuli in the RVF in children older than seven. Pilot work indicated that the task used in the study was very difficult for children younger than about five and one-half to six years old. Since it was therefore impossible to test children younger than five, males in the first, second, and third grades were used in the study. The rationale for this was that since boys lag considerably behind girls in development at this age (Ounsted & Taylor, 1969), they might undergo the transition at an age when it might already be complete in girls. The exclusive use of male subjects also controls for the possibility suggested by Buffery and Gray (1969) that there are sex differences in the development of asymmetries of cerebral function.

In order to ensure a subject population as consistent as possible in both direction and degree of cerebral asymmetry and thereby avoid the necessity of using a large number of subjects and a complex multivariate design, only strongly right-side dominant males with no familial history of left-handedness were used. A strong relationship between right hand

dominance and left hemisphere speech dominance has consistently been found (see review above). The familial history of handedness also seems to have an effect on patterns of cerebral asymmetry. Satz, Achenbach, and Fennel (1967) found that the incidence of familial left-handedness was nearly twice as great in both left and right-handers who showed speech representation on the same side as the dominant hand. Hécaen and Sauguet (1971) report that left-handers with a family history of left-handedness showed language disturbance with nearly equal frequency following unilateral left or right sided cerebral lesions. Zurif and Bryden (1969) found that left-handers with familial sinistrality did not exhibit the usual RVF superiority for verbal stimuli. Hines and Satz (1971) found a lack of visual asymmetry in right-handers with a familial history of sinistrality, and McKeever, Deventer, and Suberi (1973) report a similar finding.

Although several studies have found no effect of the familial history of handedness on cerebral asymmetries (Briggs & Nebes, 1976; Bryden, 1973 the number of studies which have shown an effect make it likely that this variable has some influence on patterns of cerebral dominance. In order to be as conservative as possible in the attempt to utilize a subject pool with a consistent pattern of cerebral dominance, only right-handers with no familial history of sinistrality were used. A similar caution dictated the use of only right-eye dominant subjects since Kershner (1971) found a difference in performance on a spatial task favoring children with mixed eye-hand dominance. He suggested that this superiority was due to a difference in cerebral asymmetry.

A number of studies have demonstrated an increased laterality effect when a memorial component was included in the task. Hines, Satz, and Clementino (1973) found that increasing the amount of material to be remembered and increasing the inter-stimulus interval increased the asymmetry between the visual fields. They suggested that the RVF superiority for verbal stimuli resulted from the memorial aspects of the task. Wilkins and Stewart (1974) report a similar finding of an increased RVF advantage for letter recognition at long (990msec) as opposed to short (50 msec) inter-stimulus intervals. Fontenot (1973) and Dee and Fontenot (1973) report a comparable enhancement of a LVF advantage for the recognition of complex forms of low verbal association value. Their finding of an optimal LVF superiority at a ten second delay interval both demonstrates the existence of a non-verbal memory system capable of spanning this time period and emphasizes the importance of a memorial component in the visual field asymmetries. The present study utilized a five second inter-stimulus interval between the presentation of a picture in central vision and the unilateral presentation of either the same or a different picture in the left or right visual field. A five second interval was selected through pilot work as being short enough to not overtax the attention span of the young subjects used in the study, but long enough to permit decay of a possible short term sensory store (Sperling, 1960) and to ensure that a memory component was present in the task.

In order to control for the left hemisphere's superiority for verbal output, a manual response was required (left hand same, right hand different for half the subjects; the converse pattern for the other half). In an

attempt to minimize somewhat the advantages which have been found for responses toward the side of stimulation (Callan et al., 1974; Richard, et al., 1973; Wallace, 1971), the required response was a lever pull toward the subject's body. The subject viewed a simple line drawing of an object for ten seconds in central vision. It was then removed and five seconds later (following a verbal warning), a picture was flashed in the left or right visual field. The subject responded 'same' or 'different' by pulling the appropriate lever. In half of the trials the second picture was the same as the first; in the other half of the trials, half of the time the second picture's name rhymed with the first picture's (e.g., clock, sock); on the other half of the 'different' trials, the two pictures' names did not rhyme. It was hypothesized that the phonetic similarity between the names of the pictures whose words rhymed would result in longer reaction times to these stimuli in the left but not in the right hemisphere. It was further hypothesized that an initial right hemisphere superiority would give way in the older children to a left hemisphere superiority. This change would reflect the shift from non-verbal to verbal processes hypothesized to occur around this time (Conrad, 1971); White, 1965).

Method

Subjects

The subjects were 18 male, right-handed school children, 6 each from the 1st (mean age = 6 years, 9 months), 2nd (mean age = 8 years), and 3rd grades (mean age = 8 years 10 months). They were selected from those right-handed boys in the first 3 grades who returned a permission slip from their parents. The permission slip contained questions relating to the familial handedness of the child. Only those boys whose parents and siblings were also right-handed were used in the study. All right-handed boys who returned a permission slip and who had no familial history of left-handedness, were tested for hand, foot, and eye dominance. The boys were observed while writing their names, cutting with scissors, and throwing a ball; they were asked to pantomime eating, hammering, and brushing their teeth. Only those boys who used their right hands for all six tasks were utilized in the study. The boys were asked to kick a ball several times, and all but one of the subjects retained in the study used their right foot. One boy showed an inconsistent foot preference. The boys were also given a rolled-up sheet of paper and were asked to use it as a 'telescope' and tell how many fingers the experimenter was holding up. All of the subjects used their right eye on each of several trials. All subjects were Caucasians and were enrolled in a private, Catholic school in a predominantly middle class area.

Apparatus

Stimuli were presented in a Polymetric Company two-field tachistoscope (model V-0959-T). Response latencies were recorded on a Lafayette timer wired to begin the timing interval with stimulus offset and terminate

it when either of two toggle switches were tripped by the subject. The stimuli used were six simple line drawings of common objects (moon, spoon, tie, pie, clock, sock) drawn in black and mounted on white cardboard. Three sets of stimuli were used; one set with the stimuli centered, one set with the right edge of the drawing offset 3° of visual angle from the center of the visual field, and one set with the left edge of the drawing offset 3° of visual angle from the center. The drawings themselves subtended about 3° of visual angle.

Procedure

All subjects were individually tested in a quiet, dimly-lit room provided by the school. Each subject participated in one or more training sessions during which it was ascertained that the subject was using the correct names for the drawings. This ensured that the names used actually rhymed (e.g., 'clock' and 'sock' rather than 'watch' and 'foot'). Very few corrections were necessary as the majority of subjects used the correct names spontaneously. During the training sessions the subjects were also familiarized with the apparatus and were given practice on the experimental task. An exposure interval of 30 msec was found during the training sessions to yield an error rate of about 10% and was used throughout the study.

For each experimental session the subject was retrieved from his classroom and seated before a low table upon which the tachistoscope rested. By leaning slightly forward, the subject placed his head against a rubber hood surrounding the viewing field of the tachistoscope. Viewing was binocular. The subject held a response panel on his lap with one hand on each of its two large toggle switches. The response panel was 48.26 mm long by 17.78 mm wide with the toggle switches set 17.78 mm apart.

Each trial was initiated by the placing of a stimulus, centered in the visual field, into the tachistoscope. The subject viewed the drawing for approximately ten seconds. A verbal warning was then given and the drawing was removed, exposing an X in the center of the visual field. Five seconds after the removal of the first stimuli (interval timed by a stopwatch) the second stimuli was flashed for 30 msec in the left or right visual field. The presentation of the second stimulus was preceded by the verbal warning "Watch the X. . . .Here it comes. . . . Right now." The subject was required to pull one toggle switch if the second stimulus was the same as the first and the other if it was different. Half of the subjects were randomly assigned to respond 'same' with the right hand and 'different' with the left hand, and half of the subjects responded with the opposite pattern. The pulling of the toggle switch turned off the timer which had been turned on by the offset of the second stimulus.

On half of the trials the second stimulus was the same as the first, and on half it was different. On half of the 'different' trials the name of the second stimulus rhymed with the name of the first stimulus. On the non-rhyming different trials the same two stimuli were always paired. This was done to ensure that the frequency of presentation of

non-rhyming pairs was the same as that of the rhyming pairs. For example since 'moon' was always followed by 'spoon' on rhyming trials, it was always followed by the same stimulus ('tie') on non-rhyming trials.

Each stimulus, when presented first was thus followed by an identical stimulus on half of the trials, by a different stimulus with a rhyming name on one-fourth of the trials, and by a stimulus with a non-rhyming name on the other one-fourth of the trials. For the six stimuli used, this resulted in a set of 24 stimulus pairs. Presentation of the second stimulus in each pair in both the left and right visual fields resulted in a block of 48 stimuli. This block of 48 stimuli was presented to each subject twice with a different randomization being used for the first and the second presentations.

Each experimental session consisted of the presentation of about 24 stimuli and lasted approximately 20 to 25 minutes. If an error was made on a trial, the trial was repeated several items later. It frequently occurred that subjects who had been responding with long average latencies and many errors in early sessions would later begin responding much more consistently and with greatly reduced latencies. Since the variability resulting from combining the very different early and late sessions could easily wash out subtle differences in reaction times, it was deemed necessary to rerun earlier sessions when they were very different from later ones. A rought criterion was adopted of rerunning a session if the error rate exceeded 25%, or if a difference in average latency exceeding 100 msec occurred from one session to the next. Altogether 10 sessions were rerun (out of 72 total sessions), 5 in the 1st grade, 4 in the 2nd, and 1 in the 3rd. No subject had more than one session rerun.

Verbal praise was freely given during each session and an attempt was made to make the task as gamelike and enjoyable as possible. The subjects seemed to find the task intrinsically interesting and the sessions were short enough and infrequent enough (about once or twice a week for each subject) to not be overly boring. Following the completion of the tachistoscopic task all subjects were individually given the Peabody Picture Vocabulary Test. One subject moved from the city before the Peabody could be administered to him. An estimate of his mental age given by the teacher was used for this subject.

Results

The latency scores were the measure of interest since the stimulus exposure interval had been selected to yield an error rate of approximately 10%. The actual error rate was 12.5% overall. By grade the error rate was: 14.93% for the first grade, 9.54% for the second grade, and 13.0% for the third grade. The mean latency scores for each subject are shown in Table 1 (for correct trials only). A repeated measures analysis of variance (ANOVA) was computed for this data. There were two between subject variables--grade and response pattern (left hand same, right hand different

and the opposite pattern)--and three within subject variables--visual field, same/different, and block. Significant main effects were found for grade, $F(2,12) = 18.74$, $p < .001$, and for same/different, $F(1,12) = 8.79$, $p < .05$ (see Table 2). The effect for grade reflected the fact that latencies decreased with increasing age, and the effect for the same/different factor was due to the superiority of 'same' judgments. The result of major interest was a highly significant interaction between grade and visual field, $F(2,12) = 8.92$, $p < .005$. This significant interaction reflected a shift from a LVF advantage in the first-graders to a RVF advantage in the second and third graders (see Table 3).

An individual analysis was performed on the scores for each grade. These analyses had only one between factor--response pattern--but the same three within subject factors as the overall analysis. Visual field was significant only in the first grade, $F(1,4) = 29.53$, $p < .01$, reflecting the large LVF superiority found at this grade level. Visual field was not significant in the second $F(1,4) = .97$, $p < .38$, nor in the third grade $F(1,4) = 2.57$, $p < .18$. The same/different factor approached significance for the third-graders, $F(1,4) = 7.54$, $p < .10$, and the block variable reached significance in this grade $F(1,4) = 12.40$, $p < .05$, indicating a practice effect.

Separate analyses were carried out on the 'same' scores and on the 'different' scores. This was done because of the significant main effect found for same/different in the overall analysis and also to allow assessment of the rhyming variable, since this variable was contained only within the different scores. The different score analysis had the same design as the overall analysis except that rhyming/non-rhyming replaced same/different as a within subjects factor. As in the overall analysis, grade was significant, $F(2,12) = 20.51$, $p < .001$; as was the grade by visual field interaction, $F(2,12) = 12.96$, $p < .005$ (see Table 4). The rhyming factor was not significant, nor was the rhyming by visual field interaction. The interaction between the rhyming variable and response pattern was significant $F(1,12) = 7.80$, $p < .05$; as was the visual field by response pattern interaction, $F(1,12) = 9.60$, $p < .01$ (see Table 5).

The ANOVA performed on the 'same' data had the same design as the overall analysis except that one within factor (same/different) was absent. In this analysis only grade was significant, $F(2,12) = 15.75$, $p < .001$ (see Table 6). Inspection of Table 3 reveals that 'same' scores did not undergo the switch from a LVF to a RVF advantage that the 'different' scores underwent.

In Figure 1, the latency scores are plotted graphically by visual field and responding hand. A different pattern is apparent in the first-graders than in the second and third-graders. The first-graders show a LVF superiority regardless of responding hand, whereas the second and third-graders show a pattern of superior performance when the responding hand is on the same side as the visual field in which the stimulus is presented. An analysis was carried out to assess the effect of responding hand. The between group variables were the same as before, and the within group variables were visual field, responding hand, and block. Once again grade and the grade by visual

field interaction were significant (see Table 7). The hand by response pattern interaction was also significant $F(1,12) = 8.75$, $p < .05$, which resulted from the fact that regardless of whether a subject was in the right-hand-same, left-hand-different group or the left-hand-same, right-hand-different group, the hand responding 'same' was faster than the hand responding 'different'. The responding hand by visual field interaction approached, but did not reach, a significant level, $F(1,12) = 2.67$, $p < .13$. A planned comparison contrasting ipsilateral visual field and hand (LVF-left hand, RVF-right hand) with contralateral visual field and hand (LVF-right hand, RVF-left hand) was not significant, $F(1,12) = .03$, and individual planned comparisons computed for each grade were also non-significant.

A measure of hemispheric superiority was computed for each subject by subtracting his overall right hemisphere (LVF) score from his overall left hemisphere (RVF) score. A correlation between this measure and the subjects' mental ages as measured by the Peabody Picture Vocabulary Test, was then computed (see Table 8). The correlation between the laterality measure and mental age was .033. The correlation between the laterality measure and chronological age was .325. ($p < .10$).

Discussion

The result of major interest is the finding that a shift in visual field superiority occurs between the first and second grades. An initial strong LVF superiority for the recognition of pictorial stimuli gives way to a later, non-significant RVF advantage. The change occurs in the seven to eight year old range and is taken as support for the hypothesis that a shift from a superiority of right hemispheric to a superiority of left hemispheric processes occurs at about this age (in boys). The hypothesis that pictures whose names rhymed would show increased reaction times because of the similarity of the verbal labels and presumed left hemispheric verbal processes was not supported.

The rhyming variable did show a significant interaction with response pattern. This resulted from the fact that those subjects responding 'different' with their left hands showed reduced latencies for the rhyming as opposed to the non-rhyming stimuli. Those subjects responding 'different' with the right hand showed the predicted increased response latency for rhyming stimuli (see Table 5). It might be argued that only those subjects responding 'different' with the right hand could be expected to show an effect for the rhyming variable since the left hemisphere controls the right hand and only in the left hemisphere is the rhyming effect hypothesized to take place. There are two problems with such an explanation however. The first is that, as Table 5 shows, in those subjects responding 'different' with their right hands, the visual field effect for rhyming stimuli is greater in the right than in the left hemisphere. Rhyming stimuli are processed much more slowly than non-rhyming stimuli in the LVF (902.2 as opposed to 846.5 msec). This would seem to indicate that the right hemisphere is more hampered by the verbal similarity of the

rhyming stimuli than the left hemisphere. The second problem is that for those subjects responding 'different' with the left hand, the rhyming stimuli were recognized faster than the non-rhyming stimuli (829.4 msec for rhyming as opposed to 849.9 msec for non-rhyming stimuli). This is the reverse of the hypothesized pattern. These considerations make it difficult to interpret the rhyming variable except to state that it did not have the hypothesized effect.

The significant visual field by response pattern interaction for 'different' judgments is easier to interpret. Subjects responding 'different' with their left hands showed a LVF advantage for different judgments whereas those subjects responding 'different' with their right hands showed a RVF advantage for such judgments. This interaction indicates that there is an advantage for responses made on the same side as that of the stimulus presentation. This effect has been reported previously (Collan et al., 1973; Wallace, 1971). The required manual response in the present study was pulling a toggle switch toward the body. This response was selected in order to minimize advantages that might result from responding toward the stimulus. Even if this manipulation had the desired effect, however, there remains the probability that reaction time is faster when the stimulus is received by the hemisphere contralateral to the responding hand (Berlucchi, Heron, Hyman, Rizzolatti, & Umiltà, 1971). 'Same' judgments show a similar enhancement for responses made to the side of stimulation. Those subjects responding 'same' with their left hands show a LVF advantage (729.5 msec as opposed to 865.4 msec), whereas those responding 'same' with their right hands showed a RVF advantage (773.5 as opposed to 799.3 msec). The interaction between visual field and response pattern did not reach significance for the 'same' responses however.

The overall analysis showed the main effects of grade and same/different to be significant. The effect for grade was due to a decrease in response latency with increasing age. This is not a surprising finding since manual speed is known to increase with age (Annett, 1970). The finding of a decrease in latency of response to visual stimuli with increasing age does not explain why responses are faster to LVF stimuli in first-graders but faster to RVF stimuli in older children. The significant main effect found for the same/different factor speaks more directly to this question.

When separate analyses were carried out on the 'same' and the 'different' responses it was found that the significant visual field by grade interaction found in the overall analysis was due solely to the 'different' scores. There was a LVF advantage for 'same' responses in the first grade (1010.7 vs 1065.3 msec), no field advantage in the second grade, and a slight LVF advantage again in the third grade (see Table 3). This pattern of results suggests that the recognition that two stimuli are identical is a task performed slightly better by the right hemisphere.

A number of studies have found that when pairs of letters are presented peripherally, there is a LVF advantage for physically identical (AA) letter pairs, and a RVF advantage for physically different letter

pairs with the same name (Aa) (Cohen, 1972; Geffen, Bradshaw & Nettleton, 1972). Egeth and Epstein (1972) have suggested that 'same' responses may require wholistic perceptual processing and therefore show a right hemis pheric advantage. Different judgments may require analytic processing and thus show a left hemisphere advantage. Wilkins and Stewart, (1974) have suggested that an initial non-verbal code, capable of mediating 'same' judgments, is available in the right hemisphere and is superceded by a left hemispheric verbal code at slightly longer intervals. Moscovitch(1976), however, offers evidence that pictural and phonemic processing go on in parallel rather than phonemic processing beginning only after the completion of non-verbal processing.

The latency data obtained from the older children in the present study is very similar to the results of studies using adult subjects, i.e., a LVF advantage for 'same' and a RVF advantage for 'different' judgments. The first-graders however showed a LVF advantage for both 'same' and 'different' judgments. "same' judgments were faster than 'different' judgments at all grade levels. This pattern of results suggests that 'same' judgments are made most efficiently by the right hemisphere regardless of age, and that 'same' judgments can always be made faster than 'different' judgments. "Different' judgments are also initially made more efficiently in the right than in the left hemisphere. At about age seven (in right-handed boys) the left hemisphere begins to mediate 'different' judgments more efficiently than the right hemisphere. This transition is possibly due to the maturation in the left hemisphere at this age of a mechanism specialized for analytic processing. The right hemisphere apparently retains a superiority for 'same' judgments and probably also the capability for making ' different' judgments. The relative superiority of the left hemisphere for 'different' judgments would result in a left hemispheric control of output mechanisms when such judgments are made.

The correlation of the laterality measure (obtained by subtracting LVF scores from RVF scores) with chronological age, ($\underline{R}$ = .325), was much higher than the correlation between the laterality measure and mental age ($\underline{R}$ = .033) as measured by the Peabody Picture Vocabulary Test. It is possible that this simply reflects the inexperience of the experimenter in administering the Peabody. The mental age scores seem rather high, and in one case the child receiving the highest score in his grade was rated by his teacher as actually being much lower. Nevertheless, the Peabody was designed to be administered by relatively inexperienced examiners, and the instructions on administration of the test were carefully followed. If the Peabody scores are accepted as valid, then the higher correlation of the laterality measure with chronological age than with mental age would indicate that physical maturation is more important than other factors in the five-to-seven transition. It seems possible that the shift from a right to a left hemispheric superiority is due to an increase in the efficienty of verbal processing (see below). Such an increase in verbal efficiency would no doubt be influenced by such factors as the richness of early language experience and the amount of verbal practice the child receives. The relatively large increase in verbal processing ability hypothesized to occur at about the age of seven could, however, be ultimately dependent upon the physical maturation of the brain mechanisms mediating verbal behavior.

In this view, the shift from a right to a left hemispheric superiority could not occur without a prerequisite level of brain maturation. Such factors as early language experience, practice, and differences in educational opportunity would then determine how soon the shift actually occurs after it becomes physically possible.

As noted in the introduction, a scan mechanism is sometimes offered as an explanation of lateral visual asymmetries. It has been argued that the left-to-right reading habits in Western countries biases perceptual scan in this direction (Heron, 1957). Several studies however have found a left-ro-right perceptual scan in young children with little or no reading experience (Gottschalk, Bryden, & Rabinovitch, 1964; Matheny, 1972). Aaron and Handley (1975) found that children as young as three years old used organized and systematic strategies in perceptual exploration. They found a preference for right-to-left responses in younger children that gave way to a preference for left-to-right responses in older children. The shift occurred by about age four in girls and about age six in boys. This finding of a later shift in boys than in girls supports the rationale of using only boys in the present study because of the necessity of using children older than about five.

The finding of a shift from a preference for right-to-left responses to a preference for left-to-right responses in boys at about age six is interesting in light of the results of the present study. If a post-exposural scan is assumed to mirror the observed change in overt perceptual scan, then a post-exposural scan starting at a central point and sweeping to the left would be expected to yield an advantage to stimuli in the LVF. A change to a left-to-right scan in boys at about the first grade level would then result in a shift to a RVF advantage. A post-exposural scan explanation of lateral perceptual asymmetries is not completely adequate (Barton et al., 1965; Bryden, 1966) particularly in the present study, where 'different' but not 'same' scores underwent a transition from a LVF to a RVF superiority; but the coincidence of a change in the direction of visual scan and a change in visual field superiority occurring at about the same age in boys is highly suggestive. Both Aaron and Handley and the present author believe that the shift is related to the phenomenon of lateralization of function in the human brain.

More precisely, the results of the present study clearly support the hypothesis that between the ages of five and seven a change takes place in the relative efficiency of the hemispheres for the recognition of pictorial stimuli. This change is assumed to be associated with (and possibly to underlie) the many behavioral changes which have been reported to take place in the five to seven age range (White, 1965). The transition from significantly faster reaction times to stimuli presented in the LVF of first-graders to significantly faster reaction times to RVF stimuli in the second-graders suggests that in right-handed boys an initial right hemispheric superiority for this task at about the age of seven. The right hemisphere has often been shown to be better at the processing of visual-spatial or non-verbal stimuli, and the left hemisphere better at the processing of verbal stimuli. The change from a LVF to a RVF advantage at about the age of seven could therefore be interpreted as a transition from a relative

superiority for non-verbal to a relative superiority for verbal processing. A similar hypothesis has been offered to explain the many changes in learning and other behaviors that take place in this age period (Kendler & Kendler, 1962; Kuenne, 1946; Conrad, 1971). The results of the present study suggest that these behavioral transitions reflect a change in the relative efficiency of the hemispheres for information processing. More specifically it seems probable that in this age period previously less efficient left hemispheric verbal processes come to surpass right hemispheric processes which have an initial superiority.

A reliance on non-verbal processes early in the left of the child would be expected since the acquisition of language is a long and complex process. Piaget((1952), among others, has demonstrated that the child, prior to the time of full acquisition of language, does not lack higher cognitive processes, but rather utilizes mental strategies that have a different character than those utilized in later life. Piaget has characterized the thought processes of the young child as being dependent upon an "intuitive" grasp of the relations between objects. Bruner (1966) describes the cognitive processes of children younger than about seven as "iconic" in the sense of relying heavily upon sensory imagery. Both theorists postulate that imaginal processes develop earlier than verbal abilities and that the transition to predominantly verbal processes occurs at about five to seven years of age. Forisha (1975) studied the development of verbal processes and mental imagery and found that before the chronological age of seven, mental age correlated highly with scores on tests of imaginal abilities, but hardly at all with verbal scores. She interpreted this finding as resulting from the lack of full development of the verbal system before the age of seven. The earlier development of imaginal processes along with the right hemisphere's superiority of visual-spatial processing, suggests that children younger than seven depend predominantly upon right hemispheric processes.

A rather large mass of data (reviewed in the "Introduction") points to a very early age of lateralization of linguistic abilities to the left hemisphere. The anatomical findings of a larger cortical expanse in the left hemispheric speech areas of infants (Wada, 1974; Witelson & Pollie, 1973) along with other findings (Eimas et al., 1971; Molfese et al., 1975) suggests the possibility that the left hemisphere has a wired-in linguistic mechanism predisposing it to verbal processing. A number of authors have suggested that the left hemispheric dominance for both handedness and speech results from a superiority of the left hemisphere for the control of sequentially organized motor activity (Geschwind, 1975; Kimura, in press; Semmes, 1969; Shankweiler & Studdert-Kennedy, 1975). Such a suggestion does not necessarily imply a motor theory of speech perception which holds that speech perception is related in a basic way to speech production, at least at higher cortical levels (see, for example, Liberman, 1974).

Palermo (1975) discusses problems with a motor theory of speech perception and argues convincingly that it is speech perception rather than production which is innate and lateralized to the left hemisphere. He notes that it is now well established that speech-sound discrimination occurs long before speech production, and that lateralization of function is present

just as early in life. He offers the hypothesis that speech production is mediated by processes involved in the perception of speech rather than vice-versa. In this view, the wired-in linguistic mechanism would mediate the categorical perception of speech sounds in infants. Speech acquisition would involve the mapping of motor production patterns onto speech-sound discriminations already innately available (and the learning of the phonological rules of one's own language).

Pur more simply, Palermo hypothesizes that the left hemisphere has the innate capacity to perceive speech sounds categorically, i.e., in terms of distinct phonemic classes. As children develop neuromuscular control of their speech apparatuses, it becomes possible for them to produce the sound differences they have long perceived. This hypothesis does not conflict with the hypothesis that the left hemispheric dominance for speech results from its superiority for the control of sequential motor activity. It has been suggested that since the speech musculature is unitary, lateralized control of speech by one hemisphere is highly efficient in that it avoids bilateral hemispheric competition for the control of a unitary output system (Levy, 1969). This being the case, the hypothesized left hemispheric superiority for the control of sequential motor behavior would efficiently lead to a left hemispheric dominance for speech production as well as speech perception.

In this view the left hemispheric dominance for speech would result from two separate but related processes. The first would be an innate human capacity for the categorical perception of speech sounds. This perceptual linguistic mechanism would explain the greater auditory evoked potential found in the left hemisphere's response to speech stimuli in children as young as two weeks of age (Molfese et al., 1975). Lieberman (1973) has found that it takes about six months for the supralaryngeal vocal tract to assume the bent shape which is apparently necessary for speech production. As the articulatory mechanism matures and develops along with the neuromuscular coordination necessary for its control, the second process--the superiority of the left hemisphere for the control of sequential motor behavior--would lead to the unilateral control of the speech musculature. The left hemisphere's sensory dominance for the categorical perception of speech sounds thus comes to be matched by a motor dominance for speech production. Marler (1975) has suggested that improvements in a child's babbling may reveal a growing skill in the matching of vocal output to auditory templates through the use of auditory feedback. The auditory templates in Marler's system are the innate mechanisms which mediate the categorical perception of speech. Continued practice in the matching of speech production with the auditory templates results in the modification and enrichment of the templates which allows even finer discriminations to be made.

It is possible that the left hemispheric dominance for both the perceptual and the motor aspects of speech in most people results from a difference in the neural organization of the two hemispheres. The more focal organization of the left hemisphere posited by Semmes might optimally subserve both language functions. It is also possible, however, that the mechanism responsible for the categorical perception of speech and the mechanism responsible for the unilateral control of the speech musculature could be lateralized to

different hemispheres. This could lead to mixed patterns of language dominance with, for example, a left hemispheric capacity for categorical speech perception and a right hemispheric superiority for the control sequential motor behavior. The right hemispheric superiority for the control of sequentially organized motor behavior would result in a left hand dominance and control of the speech mechanism by the right hemisphere.

The possibility that the mechanisms mediating cerebral dominance for speech perception and for speech production might be lateralized to different hemispheres could explain the findings of Satz et al., (1967) who reported that left hand dexterity was not associated with a particular speech dominance pattern as measured by a dichotic listening technique. Right hand dominance was more consistently associated with a left hemispheric dominance for speech perception. Annett (1975) has proposed, and strongly supported with clinical data, a genetic model of handedness and cerebral dominance for speech. She sees cerebral dominance for speech and for handedness as two independently distributed factors. A genetically determined bias facilitates a left hemispheric speech dominance, and the lateralization of speech to the left gives a slight incidental bias to the right hand, sufficient to shift the distribution of differences between the hands in a dextral direction. Thus cerebral dominance for speech and for handedness are related only in the sense that two chance and independent distributions are biased by the same factor. The main difference between Annett's model and the one offered here is that she sees cerebral dominance for language as a unitary process, whereas it seems more likely that it is actually divided into a perceptual and a productive dominance, and that only the perceptual component is separable from handedness.

In line with Annett (1975), it seems possible that a genetically transmitted factor might bias the lateralization of both cerebral dominance for speech perception and cerebral dominance for the control of sequential motor behavior to the left hemisphere. (A more focal organization of the left hemisphere could have such an effect.) In the absence of this factor, the lateralization of dominance for both speech and sequential motor behavior would depend upon random factors. Those people with right hand dominance would therefore generally (but not always) show a left hemispheric dominance for speech perception since the factor biasing hand dominance to the left hemisphere biases dominance for speech perception to the left hemisphere also. Those people with a left hand dominance would lack the factor biasing both speech perception and superior control of sequential motor behavior to the same hemisphere and would therefore show the more diverse pattern for left-handed subjects found in the Satz et al., study.

One result of a possible dissociation of cerebral dominance for speech perception and for control of sequential motor activity is that dichotic and tachistoscopic techniques would be tapping different processes. Dichotic testing would reveal which hemisphere was dominant for speech perception, whereas tachistoscopic presentation of lateralized visual stimuli would reveal nothing about the lateralization of speech perception. The RVF advantage generally found for verbal stimuli might result from the utilization of an articulatory short term memory code. Support for this suggestion comes from several studies which have shown an increased RVF advantage for verbal material as the memory requirements of the task were increased (Hines

et al., 1973; Wilkins & Stewart, 1974). The dissociation of laterality effects measured by dichotic and tachistoscopic techniques would explain the failure of two studies (Bryden, 1965; Zurif & Bryden, 1969) to find a significant correlation between dichotic listening and tachistoscopic measures of laterality. Hines and Satz' (1974) finding of a significant correlation between tachistoscopic and dichotic measures in right-handers but not in left-handers could be explained by the hypothesis that left-handers lack the factor biasing both speech perception and production to the same hemisphere. Since the dichotic measure would depend upon perceptual mechanisms and tachistoscopic measures would depend more upon productive mechanisms (articulatory short term memory), right-handers would show a correlation between the two measures, whereas left-handers would not. One further result of a separation of perceptual and productive linguistic abilities would be that the dichotic technique and the Wada technique could yield different measures of cerebral dominance, particularly in left-handers, since one measures perceptual and the other productive dominance.

The finding of a shift in the relative efficiency of the hemispheres for the processing of easily verbally coded visual stimuli could be interpreted as resulting from a change at about the age of seven, in productive verbal abilities which are dependent upon the control of sequential motor behavior. Numerous studies have found that receptive verbal abilities are lateralized at a very early age, probably from birth. The finding of a shift from a LVF to a RVF superiority between the first and second grades reflects a change in productive abilities that could be interpreted in one of several ways. It could be hypothesized that at about this age control of the speech musculature completes a process of lateralization. The resultant complete control of the articulatory mechanism by one hemisphere could greatly facilitate verbal productive abilities since there would no longer be bilateral competition for control of the speech apparatus. Alternatively, control of the speech musculature could be lateralized to one hemisphere from a very early age. The shift found in visual field superiority at age seven would, then, reflect a maturation of the neuromuscular processes controlling sequentially organized motor behavior.

The small amount of evidence relevant to this question seems to support the latter hypothesis. Denckla (1974) studied the development of motor coordination in normal, right-handed children aged five to eleven. She found a significant increase in speed of motor performance on a number of tasks with increasing age. She also found that a relative plateau was reached at about the age of eight. There were large differences in the performance of five, six, and seven-year-old children as compared to relatively small changes after this age. Denckla states that "this leveling off after the five to seven year age range is interesting in the light of the similar curve for brain growth itself, perhaps justifying the inference that the simple coordination tasks studied here are reflecting intrinsic brain maturation." She found a pattern in right-preferring children of an early establishment of right sided function, followed by a rapid increase in left sided function which resulted by age eight in a right-preferring population with only a very small right side superiority. Denckla favors an hypothesis of late maturing interhemispheric connections to explain the leveling off of motor coordination at about age eight. The fact that right sided preference was established early and that differences

between the hands decreased with age would seem to argue against the completion at age eight of a lateralized control system for the speech musculature. It seems most likely therefore that at this age in boys there is a maturation of an already lateralized process which mediates cerebral dominance for sequential motor activity.

There is a discrepancy between theories positing a late age of completion of lateralization (Lenneberg, 1967) and the model offered here. The present model considers cerebral dominance for language to be based upon two separable processes. The first is a dominance for the categorical perception of speech stimuli which is innate and lateralized from birth. The second process is a cerebral dominance for the control of sequentially organized motor behavior which leads to both an asymmetry in manual skill and unilateral hemispheric control of the speech musculature. Since there is evidence that consistent manual dominance is established at about nine months (Seth, 1973) it is probable that control of the speech mechanism is lateralized at about this age also.

The possibility that the speech mechanism is not developed enough allow speech production until about six months of age (Lieberman, 1973) leads to the interesting speculation that it is the lateralization of control of the speech mechanism to one hemisphere which leads to a cerebral dominance for the control of sequential motor activity. The efficient control of the unitary speech mechanism would seem to demand unilateral hemispheric control of speech production rather than bilateral hemispheric competition. This lateralization would presumably not occur until the articulatory mechanism was mature enough to produce speech, although a genetic bias would predispose lateralization to a particular hemisphere. Continued practice in controlling the articulatory mechanism would give one hemisphere an advantage over the other for the control of sequential motor behavior. Thus, in most cases, a left hemisphere dominance for the control of the speech musculature would begin to be seen at about six months of age when the articulatory mechanism matured enough to allow speech sounds to be made. Continuing practice in the control of the speech musculature would give the left hemisphere a superiority in the control of motor sequences that would lead to the establishment of manual dominance at about nine months of age. As the child matured however, continuing motor experience with both sides of the body would lead to increased skill in the right hemisphere and the decreasing asymmetry in manual ability that has been demonstrated in several studies (Annett, 1970; Denckla, 1974).

Whatever the mechanism may be which determines cerebral dominance for handedness, it is clear that hand preference is established at a very early age. According to the present model this would mean that control of speech production would be lateralized at an early age also. The clinical data indicating that language dominance is more easily shifted to the opposite hemisphere following cerebral damage in children than in adults (Hécaen, 1976) may indicate nothing more than that the brain is more plastic in children than in adults. Although both speech perception and production are lateralized at an early age, they may be displaced to the opposite hemisphere following cerebral injury before a certain critical age. Lenneberg argues that lateralization is not complete until puberty. It is more

likely, however, that lateralization is completed very early but that reorganization of lateralized abilities can take place until the end of a period of cerebral plasticity. Puberty might then be the age at which lateralized abilities are "stamped in" and no longer subject to reorganization in the other hemisphere.

The present study demonstrated a shift from a LVF to a RVF superiority at about the age of seven in right-handed boys. The author's interpretation of this finding in relation to other relevant findings is as follows. A genetic factor biases the lateralization of an innate mechanism mediating categorical speech perception to the left hemisphere. The same factor independently biases the lateralization of a mechanism determining unilateral control of the speech musculature and manual dominance to the left hemisphere. The majority of people would thus be left hemisphere-dominant for both speech perception and speech production. In the absence of the genetic factor, the lateralization of speech perception and production would depend upon random factors. This analysis follows that of Annett (1975) very closely with the exception that her model discusses the distribution of handedness and a unitary dominance for language, whereas the the present model divides language dominance into separate processes for speech perception and speech production. The factor determining cerebral dominance for speech production would also determine manual dominance. The predicted distribution of cerebral dominance for speech perception would be the same as that of Annett's for language dominance. The predicted distribution of hand dominance would be the same as Annett's but would additionally be the predicted distribution for dominance of speech production since cerebral dominance for handedness and speech production are hypothesized to be dependent upon the same mechanism.

Lateralized control of the speech musculature would be highly efficient in that it would avoid bilateral competition for control of a unilateral mechanism. It would also leave one hemisphere free for the efficient control of behavior while the other hemisphere was burdened by the slow process of language acquisition. Speech acquisition would involve a reciprocal interaction between perceptual and productive capacities. Auditory feedback would be utilized to shape speech utterances into phonetic categories determined by innate auditory "templates." The templates would themselves be modified and refined by this feedback loop so that differing native language communities would be sensitive to subtle differences within innately determined phonetic boundaries.

The development of language skills would be dependent upon several processes. Vocabulary learning would involve the association of particular articulatory motor patterns--words--with the categories of experience deemed important by the society into which the child is born. The learning of syntax would involve acquiring knowledge of the constraints upon the serial orderings of these articulatory patterns. Finally, language development would be dependent upon the physical maturation of the neuromuscular system controlling speech. The maturation of the neuromuscular system controlling speech at about the age of five to seven results in left hemispheric verbal information processing mechanisms becoming for the first time as efficient as the right hemisphere's non-verbal system. The stimuli

used in the present study were easily verbally labelled drawings of common objects. The efficient use of a left hemispheric verbal code would result in the shift from a LVF to a RVF superiority found to occur at about the age of seven in boys. The shift would presumably occur earlier in girls. Conrad (1971), among others, suggests that an articulatory short term memory process begins to be used at about the age of five to seven. The efficient use of such a system would be related to the maturation of verbal abilities at about this age and could also explain the visual field shift found in the present study. The efficient use of an articulatory short term memory code could lead to better memory of the initial stimulus and reduced latencies to RVF stimuli.

Appendix I: Statistical Tables

Table 1

Mean Latency Scores for Each Subject (In milliseconds)

Subject	Grade	Same		Different	
		RVF	LVF	RVF	LVF
1	1	1243.3	1198.1	1257.5	1170.2
2	1	1250.0	1128.8	1295.6	1270.4
3	1	1080.8	1034.8	1080.8	1032.3
4	1	1163.5	989.0	1108.8	1036.0
5	1	741.7	744.4	826.5	755.0
6	1	980.4	990.0	1215.6	1017.9
7	2	664.4	528.5	630.6	724.8
8	2	1012.3	917.3	859.7	950.4
9	2	730.4	756.7	715.4	719.0
10	2	675.8	752.7	799.2	824.6
11	2	778.0	709.6	753.1	778.3
12	2	624.0	726.9	678.1	728.5
13	3	679.0	593.8	592.3	760.2
14	3	627.7	515.8	540.0	630.6
15	3	532.0	478.9	492.9	611.9
16	3	683.3	763.5	761.7	784.0
17	3	629.0	615.6	629.0	677.1
18	3	806.5	857.7	932.7	829.4

Table 2

Overall ANOVA--2 Between 3 Within:

Grade (G) x Response Pattern (P) x Visual Field (VF) x Same/Different (S/D) x Block (B)

Source	SS	df	MS	F
G	6,363,754.00	2	3,181,877.00	18.74***
P	21,473.00	1	21,473.00	.13
G x P	1,103,633.00	2	551,816.50	3.25*
Error	2,037,638.00	12	169,803.12	
VF	81.69	1	81.69	.009
VF x G	155,155.63	2	77,577.81	8.92**
VF x P	157.25	1	157.25	.02
VF x G x P	1,701.75	2	850.87	.09
Error	104,411.50	12	8,700.96	
S/D	96,540.19	1	96,540.19	8.79**
S/D x G	4,357.94	2	2,178.97	.20
S/D x P	598.19	1	598.19	.05
S/D x G x P	2,486.06	2	1,243.03	.11
Error	131,751.25	12	10,979.27	
B	187,596.56	1	187,596.56	2.22
B x G	21,152.06	2	10,576.03	.12
B x P	56,109.56	1	56,109.56	.67
B x G x P	157,213.56	2	78,606.75	.93
Error	1,010,714.44	12	84,226.19	

NOTE: No higher order interaction was significant.

*p < .05
**p < .005
***p < .001

Table 3

Mean Latency Scores:

Grade by Visual Field by Same/Different

	Same			Different			
Grade	RVF	LVF		RVF	LVF		
1	1065.3	1010.7	1038.0	1130.8	1046.9	1088.8	1063.4
2	733.4	739.5	736.4	739.8	784.2	762.0	749.2
3	659.6	637.9	648.8	658.0	715.6	686.8	667.8
	951.6	924.4	938.0	978.8	985.7	982.3	826.4

Table 4

ANOVA of 'Different' Data--2 Between, 3 Within:

Grade (G) x Response Pattern (P) x Visual Field (VF) x Rhyme (R) x Block (B)

Source	SS	df	MS	F
G	1,579,788.00	2	789,894.00	20.51***
P	1,939.44	1	1,939.44	.05
G x P	272,941.37	2	136,470.69	3.54*
Error	462,096.94	12	38,508.08	
VF	482.17	1	482.17	.24
VF x G	52,782.47	2	26,391.23	12.96***
VF x P	19,541.59	1	19,541.59	9.60**
VF x G x R	5,983.88	2	2,991.94	1.47
Error	24,432.96	12	2,036.08	
R	590.09	1	590.09	.53
R x G	3,173.49	2	1,586.75	1.42
R x P	8,922.27	1	8,922.27	7.99**
R x G x P	5,749.32	2	2,874.66	2.58
Error	13,386.20	12	1,115.51	
B	61,897.12	1	61,897.12	3.42
B x G	5,209.94	2	2,604.97	.14
B x P	12,929.50	1	12,929.50	.71
B x G x P	77,325.25	2	38,662.62	2.14
Error	216,843.69	12	18,070.30	
VF x R	1,384.47	1	1,384.47	.82
VF x R x G	866.81	2	433.41	.25
VF x R x P	1,969.14	1	1,969.14	.16
VF x R x G x P	230.07	2	115.03	.07
Error	20,343.30	12	1,695.28	

NOTE: No higher order interaction was significant.

*p < .05
**p < .01
***p < .005
****p < .001

Table 5

Mean 'Different' Scores:
Response Pattern Interaction with Visual Field and Rhyme Variable

	Rhymes			Does Not Rhyme			Visual Field	
	RVF	LVF	Σ	RVF	LVF	Σ	RVF	LVF
I[a]	847.3	812.6	829.9	864.8	834.0	849.4	856.1	823.3
II[b]	835.1	902.2	868.6	824.3	846.5	835.4	829.7	874.4

I[a] indicates the group responding right hand same, left hand different.
II[b] indicates the group responding left hand same, right hand different.

Table 6

ANOVA of 'Same' Data--2 Between, 2 Within:
Grade (G) x Response Pattern (P) x Visual Field (VF) x Block (B)

Source	SS	df	MS	F
G	3,088,120.00	2	1,544,060.00	15.75***
P	12,680.00	1	12,680.00	.13
G x P	585.941.00	2	292,970.50	2.99
Error	1,176,061.00	12	98,005.06	
VF	1,164.00	1	1,164.00	.05
VF x G	66,864.00	2	33,432.00	1.51
VF x P	21,823.00	1	21,823.00	.99
VF x G x P	14,629.37	2	7,314.69	.33
Error	265,579.06	12	22,131.58	
B	60,002.06	1	60,002.06	1.04
B x G	5,307.37	2	2,653.69	.05
B x P	20,116.62	1	20,116.62	.34
B x G x P	22,740.87	2	11,370.44	.20
Error	690,555.50	12	57,546.29	

NOTE: No higher order interaction was significant.

*** $p < .001$.

Table 7

Hand x Hemisphere ANOVA--2 Between, 2 Within:
Grade (G) x Response Pattern (P) x Hand (H) x Visual Field (VF) x Block (B)

Source	SS	df	MS	F
G	6,322,479.00	2	3,161,239.00	18.72***
P	19,786.00	1	19,786.00	.12
G x P	1,088,139.00	2	544,069.50	3.22*
Error	2,026,569.00	12	168,880.75	
VF	222.44	1	222.44	.03
VF x G	148,826.31	2	74,413.13	8.58**
VF x P	339.19	1	339.19	.04
VF x G x P	2,440.12	2	1,220.06	.14
Error	104,114.88	12	8,676.24	
H	345.31	1	345.31	.03
H x G	1,732.06	2	866.03	.07
H x P	100,225.31	1	100,225.31	8.76**
H x G x P	4,612.50	2	2,306.25	.20
Error	137,353.38	12	11,446.11	
B	192,720.56	1	192,720.56	2.26
B x G	19,416.00	2	9,708.00	.11
B x P	53,360.56	1	53,360.00	.62
B x G x P	152,980.56	2	76,490.00	.90
Error	1,024,464.44	12	85,372.00	
H x VF	51,680.56	1	51,680.56	2.67
H x VF x G	18,061.94	2	9,030.97	.47
H x VF x P	3,989.94	1	3,989.94	.21
H x VF x G x P	37,287.69	2	18,643.84	.96
Error	231,765.75	12	19,313.81	

NOTE: No higher order interaction was significant.

*$p < .05$
**$p < .005$
***$p < .001$

Table 8

Chronological Age, Mental Age, and Laterality for Each Subject

Subject	Grade	CA	MA	Laterality Score[a]
1	1	7,7	12,2	-318.0
2	1	6,5	10,7	-281.0
3	1	7,0	8,11	-263.0
4	1	6,5	9,4	-593.0
5	1	7,4	12,2[b]	-165.0
6	1	7,1	8,9	-451.5
7	2	8,6	11,7	71.0
8	2	8,5	12,4	-105.0
9	2	7,5	8,8	- 11.0
10	2	8,3	10,4	145.5
11	2	7,8	8,9	312.5
12	2	7,11	8,2	317.0
13	3	9,5	12,2	198.5
14	3	8,10	9,10	- 51.0
15	3	8,8	10,9	158.0
16	3	8,8	12,2	246.5
17	3	8,10	12,4	83.0
18	3	8,7	14,5	-120.5

NOTE: Correlation of MA and laterality score: R .033
Correlation of CA and laterality score: R .325

[a]Laterality score RVF total - LVF total.

[b]Mental age score for this subject based on teacher's estimate.

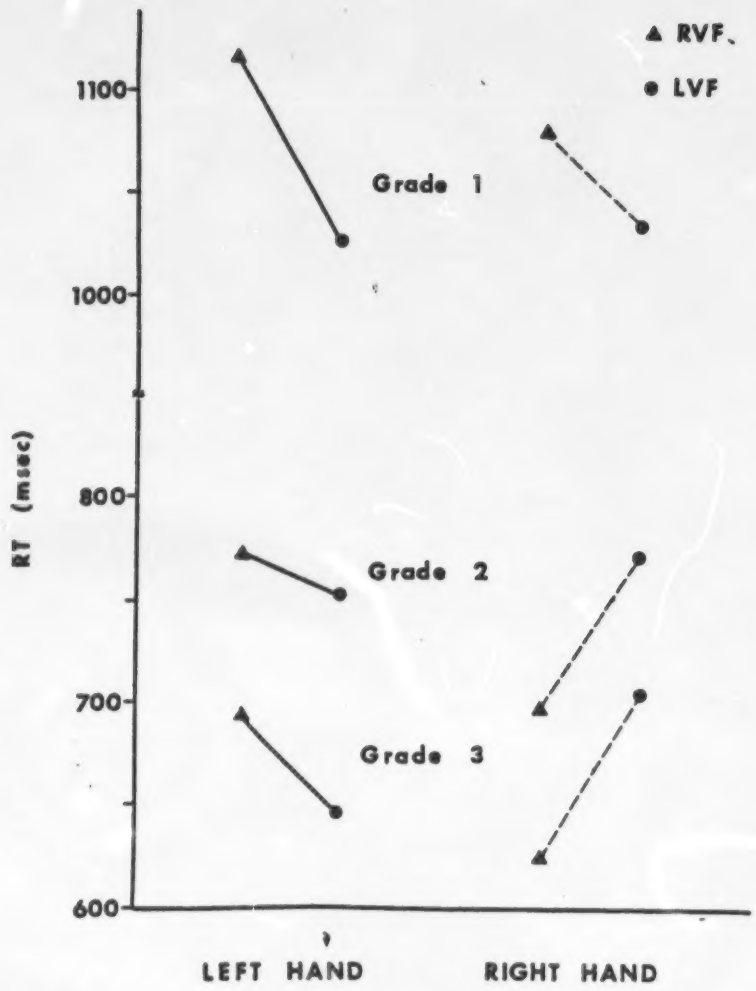

Fig. 1 - Mean reaction time as a function of grade, input field, and response hand.

REFERENCES

Aaron, P. G., & Handley, A. C. Directional scanning and cerebral asymmetries in processing visual stimuli. Perceptual and Motor Skills, 1975, 40, 719-725.

Annet, M. The growth of manual preference and speed. British Journal of Psychology, 1970, 61, 545-556.

Bakan, P. Hypnotizability, laterality of eye movements and functional brain asymmetry. Perceptual and Motor Skills, 1969, 28, 927-932.

Bartholomeus, B. Effects of task requirement on ear superiority for sung speech. Cortex, 1974, 10, 215-223.

Barton, M. I., Goodglass, H., & Shai, A. Differential recognition of tachitoscopically presented English and Hebrew words in the right and left visual fields. Perceptual and Motor Skills, 1965, 21, 431-437.

Basser, L. S. Hemiplegia of early onset and the faculty of speech with special reference to the effects of hemispherectomy. Brain, 1962, 85.

Berlin, C. I., Hughes, L. F., Lowe-Bell, S. S. & Berlin, H. L. Dichotic right ear advantage in children 5 to 13. Cortex, 1973, 9, 394-402.

Berlucchi, G. Cerebral dominance and interhemispheric communication in normal man. In F. O. Schmitt & F. G. Worden (eds.) The Neurosciences Third Study Program. Cambridge: MIT Press, 1974.

Berlucchi, G., Brizzolura, D., Camarzi, G. & Umiltà, G. Can lateral asymmetries in attention explain interfield differences in visual perception/ Cortex, 1974, 10, 177-186.

Blakemore, C. B., & Falconer, M. A. Long term effects of anterior temporal lobectomy on certain cognitive functions. Journal of Neurological and Neurosurgical Psychiatry, 1967, 30, 364-367.

Blumstein, S. & Cooper, W. E. Hemispheric processing of intonation contours. Cortex, 1974, 10, 146-155.

Bogen, J. E. The other side of the brain II: an appositional mind. Bulletin of the Los Angeles Neurological Societies, 1969, 34, 135-162.

Briggs, G. G. & Nebes, R. D. The effects of handedness, family history and sex on the performance of a dichotic listening task. Neuropsychologia, 1976, 14, 129-133.

Broadbent, D. E. Division of function and integration of behavior. In F. O. Schmitt & F. G. Worden (eds.) The Neurosciences Third Study Program. Cambridge: MIT Press, 1974.

Brown, J. & Jaffe, J. Hypothesis on cerebral dominance. Neuropsychologia, 1975, 13, 107-110.

Bruner, J. S., Olver, R. R., & Greenfield, B. M. Studies in Cognitive Growth. New York: Wiley, 1966.

Bryden, M. P. Tachistoscopic recognition of non-alphabetic material. Canadian Journal of Psychology, 1960, 15, 209-211.

Bryden, M. P. Tachistoscopic recognition, handedness and cerebral dominance. Neuropsychologia, 1965, 2, 1-8.

Bryden, M. P. Left-right differences in tachistoscopic recognition: directional scanning or cerebral dominance? Perceptual and Motor Skills, 1966, 23, 1127-1134.

Bryden, M. P. Laterality effects in dichotic listening: relations with handedness and reading ability in children. Neuropsychologia, 1970, 8, 443-450.

Bryden, M. P. Perceptual asymmetry in vision: relation to handedness, eyedness and speech lateralization. Cortex, 1973, 6, 418-435.

Bryden, M. P. & Allard, F. Visual hemifield differences depend on typeface. Brain and Language, 1976, 3, 191-200.

Bryden, M. P. & Rainey, L. A. Left-right differences in tachistoscopic recognition. Journal of Experimental Psychology, 1963, 66, 568-571.

Buffery, A. W. Sex differences in the development of hemispheric asymmetry of function in the human brain. Brain Research, 1971, 31, 364-365.

Buffery, A. W. & Gray, J. G. Sex differences in the development of spatial and linguistic skills. In L. D. Lipsitt & C. C. Spiker, Advances in Child Development and Behavior. New York: Academic Press, 1965.

Butler, S. & Norrsell, U. Vocalization possibly initiated by the minor hemisphere. Nature, 1968, 220, 793-794.

Butters, N., Soeldner, C. & Fedio, P. Comparison of parietal and frontal lobe spatial deficits in man: extra-personal vs. personal (egocentric) space. Perceptual and Motor Skills, 1972, 34, 27-34.

Callan, J., Klisz, D. & Parsons, O. A. Strength of auditory stimulus-response compatibility as a function of task complexity. Journal of Experimental Psychology, 1974, 102, 1039-1045.

Caplan, D., Holmes, J. M., & Marshall, J. C. Word classes and hemispheric specialization. Neuropsychologia, 1974, 12, 331-337.

Cohen, G. Hemispheric differences in a letter classification task. Perception and psychophysics, 1972, 11, 137-142.

Cohen, G. Hemispheric differences in serial versus parallel processing. Journal of Experimental Psychology, 1973, 97, 349-356.

Cook, R. B. Left-right differences in the perception of dichotically presented musical stimuli. Journal of Music Therapy, 1973, 10, 59-63.

Conrad, R. The chronology of the development of covert speech in children. Developmental Psychology, 1971, 5, 398-405.

Corkin, S. Tactually-guided maze-learning in man: effects of unilateral cortical excisions and bilateral hippocampal lesions. Neuropsychologia, 1965, 3, 339-351.

Corman, A. & Nachson, I. Ear asymmetry in the perception of emotional, non-verbal stimuli. Acta Psychologia, 1973, 37, 351-357.

Curry, F. K. W. A comparison of left-handed and right-handed subjects on verbal and non-verbal dichotic listening tasks. Cortex, 1967, 3, 343-352.

Dahlia, B. & Sperry, R. Performance on the Raven's Colored Progressive Matrices Test by subjects with cerebral commissurotomy, Cortex, 1973,

Darwin, C. J. Auditory dominance and cerebral dominance. (Doctoral dissertation, University of Cambridge, (1969) in F. O. Schmitt & F. G. Worden (eds.) The Neurosciences Third Study Program. Cambridge: MIT Press, 1974.

Darwin, C. J. Ear differences and hemispheric specialization. In F. O. Schmitt & F. G. Worden (Eds.) The Neurosciences Third Study Program. Cambridge: MIT Press, 1974.

Day, M. E. An eye movement phenomenon relating to attention, thought and anxiety. Perceptual and Motor Skills, 1964, 19, 443-446.

Dee, H. L. & Fontenot, D. J. Cerebral dominance and laterality differences in perception and memory. Neuropsychologia, 1973, 11, 167-173.

Denkcla, M. B. Development of motor coordination in normal children. Developmental Medicine and Child Neurology, 1974, 16, 729-741.

Dorman, M. F. & Geffner, D. S. Hemispheric specialization for speech perception in six year old black and white children from low and middle socio-economic classes. Cortex, 1974, 10, 171-176.

Durnford, H. & Kimura, D. Cerebral dominance and laterality differences in perception and memory. Nature, 1971, 231, 394-395.

Egeth, H. & Epstein, J. Differential specialization of the cerebral hemispheres for the perception of sameness and difference. Perception and Psychophysics, 1972, 12, 218-220.

Eimas, P. D., Siqueland, E. R., Jusczyk, P., & Vigorito, J. Speech perception in infants. Science, 1971, 171, 303-306.

Fontenot, D. J. Tachistoscopic recognition of verbal and non-verbal stimuli in left and right visual fields. (Doctoral dissertation, University of Iowa, 1972) in H. L. Dee and D. J. Fontenot, Cerebral dominance and lateral differences in perception and memory. Neuropsychologia, 1973, 11, 167-173.

Fontenot, D. Visual field differences in the recognition of verbal and non-verbal stimuli in man. Journal of Comparative and Physiological Psychology, 1973, 85, 564-569.

Fontenot, D. & Benton, A. L. Perception of direction in the left and right visual fields. Neuropsychologia, 1972, 16, 447-452.

Forgay, D. G. The development of differential word recognition. Journal of Experimental Psychology, 1953, 45, 165-168.

Forisha, B. D. Mental imagery verbal process: a developmental study. Developmental Psychology, 1975, 11, 259-267.

Gazzaniga, M. S. The Bisected Brain. New York: Appleton-Century Crofts, 1970.

Gazzaniga, M. S., Bogen, J. E., & Sperry, R. W. Dyspraxia following division of the cerebral commissures. Archives of Neurology, 1967, 16, 602-612.

Gazzaniga, M. S. & Hillyard, S. A. Language and speech capacity of the right hemisphere. Neuropsychologia, 1971, 9, 273-280.

Greffen, G., Bradshaw, J., & Nettleton, N. C. Hemispheric asymmetry: verbal and spatial encoding of visual stimuli. Journal of Experimental Psychology, 1972, 93, 25-31.

Geffner, D. A. & Dorman, M. F. Hemispheric specialization for speech perception in four-year old children from low and middle socio-economic classes. Cortex, 1976, 12, 71-73.

Geschwind, N. The Apraxias: Neural mechanisms of disorders of learned movement. American Scientist, 1975, 63, 188-195.

Geschwind, R. & Levitsky, H. Human brain, left-right asymmetries in temporal speech region. Science, 1968, 161, 186-187.

Gessell, A. & Ames, L. B. The development of handedness. Journal of Genetic Psychology, 1947, 70, 155-176.

Gilbert, G. & Bakan, P. Visual asymmetry in the perception of faces. Neuropsychologia, 1973, 11, 355-362.

Goldstein, L. & Lochner, J. R. Sideways look at dichotic listening. Journal of the Acoustical Society of America, 1974, 55, Supplement S10(a).

Gordon, H. Verbal and nonverbal cerebral processing in man for audition. (Doctoral dissertation, California Institute of Technology, 1973) in R. D. Nebes. Hemispheric specialization in commissurotomized man. Psychological Bulletin, 1974, 31, 1-14.

Gottschalk, J., Bryden, M. P., & Rabinovitch, M. S. Spatial organization of children's responses to a pictorial display. Child Development, 1964, 35, 811-815.

Gur, R. E., Gur, R. C., & Harris, L. J. Cerebral activation as measured by subject's lateral eye movements is influenced by experimenter location. Neuropsychologia, 1975, 13, 55-64.

Guyer, B. L. & Friedman, M. P. Hemispheric processing and cognitive style in learning-disabled and normal children. Child Development, 1975, 46, 658-668.

Hécaen, H. Acquired aphasia in children and the ontogenesis of hemispheric functional specialization. Brain and Language, 1976, 3, 114-134.

Hécaen, H. & Sauguet, J. Cerebral dominance in left-handed subjects. Cortex, 1971, 7, 19-48.

Heron, W. Perception as a function of retinal locus and attention. American Journal of Psychology, 1957, 70, 38-48.

Hicks, R. E. Interhemispheric response competition between vocal and unimanual performance in adult human males. Journal of Comparative and Physiological Psychology, in press.

Hines, D. & Satz. P. Cross-modal asymmetries in perception related to asymmetries in cerebral function. Neuropsychologia, 1974, 12, 239-247.

Hines, D., Satz, P., & Clementino, T. Perceptual and memory components of the superior recall of letters from the right visual half-fields. Neuropsychologia, 1973, 11, 175-180.

Homa, D. & Chambliss, D. Relative contributions of common and distinctive information on the abstraction from ill-defined categories. Journal of Experimental Psychology, Human Learning and Memory, 1975, 104, 351-368.

Ingram, D. Cerebral speech lateralization in young children. Neuropsychologia, 1975a, 13, 103-105.

Ingram, D. Motor asymmetries in young children. Neuropsychologia, 1975b, 13, 95-102.

Kender, H. H. & Kendler, T. S. Vertical and horizontal processes in problem solving. Psychological Review, 1962, 69, 1-16.

Kershner, J. R. Children's acquisition of visual-spatial dimensionality: a conservation study. Developmental Psychology, 1971, 5, 454-462.

Kimura, D. Speech lateralization in young children as determined by an auditory test. Journal of Comparative and Physiological Psychology, 1961, 56, 899-902.

Kimura, D. Right temporal-lobe damage. Archives of Neurology, 1963, 8, 264-271.

Kimura, D. Left-right differences in the perception of melodies. Journal of Experimental Psychology, 1964, 14, 355-358.

Kimura, D. Dual functional asymmetry of the brain in visual perception. Neuropsychologia, 1966, 4, 275-285.

Kimura, D. Manual activity during speaking 1. right-handers. Neuropsychologia, 1973, 11, 45-50.

Kimura, D. The neural basis of language qua gesture. In H. Avakian-Whitaker & H. A. Whitaker (eds.) Studies in Neurolinguistics. New York: Academic Press (in press).

Kimura, D. & Archibald, Y. Motor functions of the left hemisphere. Brain, 1974, 97, 337-350.

Kimura, D. & Durnford, M. Normal studies on the function of the right hemisphere in vision. In S. J. Dimond & J. G. Beaumont (eds.) Hemispheric Function in the Human Brain. London: Paul Eleck, 1974.

Kinsbourne, M. The cerebral basis of lateral asymmetries attention. Acta Psychologia, 1970, 33, 193-201.

Kinsbourne, M. & Cook, J. Generalized and lateralized effects of concurrent verbalization on a unimanual skill. Quarterly Journal of Experimental Psychology, 1971, 23, 341-345.

Knox, C. & Kimura, D. Cerebral processing of non-verbal sounds in boys and girls. Neuropsychologia, 1970, 8, 227-237.

Kuenne, M. R. Experimental investigation of the relation of language to transposition behavior in young children. Journal of Experimental Psychology, 1966, 36, 471-490.

Lake, D. A. & Bryden, M. P. Handedness and sex differences in hemispheric asymmetry. Brain and Language, 1976, 2, 266-282.

Lashley, K. S. The problem of serial order in behavior. In L. A. Jeffress (ed.) Cerebral Mechanisms in Behavior: The Hixon Symposium. New York; John Wiley, 1951.

Lenneberg, E. H. Biological Foundations of Language. New York: John Wiley, 1967.

Levy, J. Possible basis for the evolution of lateral specialization of the human brain. Nature, 1969, 224, 614-615.

Levy, J. Information processing and higher psychological functions in the disconnected hemispheres of human commissurotomy patients. (Doctoral dissertation, California Institute of Technology, 1970). In R. D. Nebes. Hemispheric specialization in commissurotomized man. Psychological Bulletin, 1974, 31, 1-14.

Levy, J. Psychobiological implications of bilateral asymmetry. In S. J. Dimond & J. C. Beaumont (eds.) Hemispheric Function in the Human Brain. New York: Holstead Press, 1974.

Levy, J., Nebes, R. D. & Sperry, R. W. Expressive language in the surgically separated monor hemisphere. Cortex, 1970, 74, 49-58.

Liberman, A. M. The specialization of the language hemisphere. In F. O. Schmitt & F. G. Worden (eds.) The Neurosciences: Third Study Program. Cambridge: MIT Press, 1974.

Lieberman, P. On the evolution of language: a unified view. Cognition, 1973, 2, 59-94.

Lomas, J. & Kimura, D. Interhemispheric interaction between speaking and sequential manual activity. Neuropsychologia (in press).

Marcel, A. J., Katz, L., & Smith, M. Laterality and reading proficiency. Neuropsychologia, 1974, 12, 131-139.

Marcel, T. and Rajan, P. Lateral specialization for recognition of words and faces in good and poor readers. Neuropsychologia, 1975, 13, 489-497.

Marler, P. On the origin of speech from animal sounds. In J. F. Kavanagh & J. E. Cutting. The Role of Speech in Language. Cambridge: MIT Press, 1975.

Matheny, A. P. Perceptual exploration in twins. Journal of Experimental Psychology, 1972, 14, 108-116.

McKeever, W. F., Van Deventer, A. D., & Suberi, M. Avowed, assessed and familial handedness and differential hemispheric processing of brief sequential and non-sequential visual stimuli. Neuropsychologia, 1973, 11, 235-238.

Meier, M. J., & French, L. A. Lateralized deficits in complex visual discrimination and bilateral transfer of reminiscence following unilateral temporal lobectomy. Neuropsychologia, 1965, 3, 261-272.

Milner, B. Visually guided maze learning in man: effects of bilateral hippocampal, bilateral frontal and unilateral cerebral lesions. Neuropsychologia, 1965, 3, 317-338.

Milner, B. Visual recognition and recall after right temporal-lobe excision in man. Neuropsychologia, 1968, 6, 191-209.

Milner, B. Interhemispheric differences in the localization of psychological processes in man. British Medical Bulletin: Cognitive Psychology, 1971, 27, 272-277.

Milner, B. Hemispheric specialization: scope and limits. In F. O. Schmitt & F. G. Worden (eds.) The Neurosciences: Third Study Program. Cambridge: MIT Press, 1974.

Milner, B. & Taylor, R. Right hemisphere superiority in tactile pattern-recognition after cerebral commissurotomy: evidence for non-verbal memory, Neuropsychologia, 1972, 10, 1-15.

Mishkin, M. & Forgays, D. G. Word recognition as a function of retinal focus. Journal of Experimental Psychology, 19 2, 43, 43-58.

Moffitt, A. R. Consonant cue perception by twenty-four week old infants. Child Development, 1971, 42, 717-731.

Molfese, D. L., Freeman, R. B., & Palermo, D. S. The ontogeny of brain lateralization for speech and nonspeech stimuli. Brain and Language, 1975, 2, 356-368.

Morais, J. & Bertleson, P. Laterality effects in dichotic listening. Perception, 1973, 2, 107-111.

Morrell, F. Integrative properties of parastriate neurons. In A. G. Karczmar & J. C. Eccles (eds.) Brain and Human Behavior. New York: Springer-Verlagi, 1972.

Moscovitch, M. On the representation of language in the right hemisphere of right-handed people. Brain and Language, 1976, 3, 47-71.

Nebes, R. D. Perception of spatial relationships by the right and left hemisphere in commissurotomized man. Neuropsychologia, 1973, 11, 285-288.

Nebes, R. D. Hemispheric specialization in commissurotomized man. Psychological Bulletin, 1974, 81, 1-14.

Neisser, U. Cognitive Psychology. Englewood Cliffs, New Jersey: Prentice-Hall, 1967.

Olson, M. E. Laterality differences in tachistoscopic word recognition in normal and delayed readers in elementary school. Neuropsychologia, 1973, 11, 343-350.

Orbach, J. Retinal locus as a factor in the recognition of visually perceived words. American Journal of Psychology, 1952, 65, 555-562.

Ounsted, C. & Taylor, D. C. The Y chromosome message: a point of view. In C. Ounsted & D. C. Taylor (eds.) Gender Differences: Their Ontogeny and Significance. London: Churchill Livingstone, 1969.

Palermo, D. S. Developmental aspects o speech perception: problems for a motor theory. In J. F. Kavanagh & J. E. Cutting. The Role of Speech in Language. Cambridge: MIT Press, 1975.

Papcun, G., Krashen, S., Terbeek, D., Remington, R., & Harshman, R. Is the left hemisphere specialized for speech, language and/or something else? Journal of the Acoustical Society of America, 1974, 55, 319-327.

Piaget, J. The Origins of Intelligence in Children. New York: W. W. Norton, 1972.

Pizzamiglio, L. & McChini, P. Development of hemispheric dominance in children from 5-10 years of age and their relations with the development of cognitive processes. Brain Research, 1971, 31, 363-364.

Porter, R. J. & Berlin, C. I. On interpreting developmental changes in the dichotic right ear advantage. Brain and Language, 1975, 2, 186-200.

Ratcliff, G. & Newcombe, F. Spatial orientation in man: effects of left, right and bilateral posterior cerebral lesions. Journal of Neurology, Neurosurgery, and Psychiatry, 1973, 36, 448-454.

Richard, S. J., Craft, J. L., & Webster, S. B. Reactions toward the stimulus source: analysis of correct responses over a five day period. Journal of Experimental Psychology, 1973, 101, 175-178.

Robinson, G. & Soloman, D. J. Rhythm is processed by the speech hemisphere. Journal of Experimental Psychology, 1974, 102, 508-511.

Rosch, E. Cognitive representation of semantic categories. Journal of Experimental Psychology: General, 1975, 1043, 192-233.

Satz, P., Achenbach, K., & Fennell, E. Correlations between assessed manual laterality and predicted speech laterality in a normal population. Neuropsychologia, 1967, 5, 295-310.

Satz, P., Bakker, D. J., Teunissen, J., Goebel, R., & Van der Vlugt, H. Developmental parameters of the ear asymmetry: a multivariate approach. Brain and Language, 1975, 2, 171-185.

Semmes, J. Hemispheric specialization: a possible clue to mechanism. Neuropsychologia, 1968, 6, 11-26.

Seth, G. Eye-hand coordination and "handedness": a developmental study visuo-motor behavior in infancy. British Journal of Educational Psychology, 1973, 43, 35-49.

Shankweiler, D. P. & Studdert-Kennedy, M. Identification of consonants and vowels presented to left and right ears. Quarterly Journal of Experimental Psychology, 1967, 19, 59-63.

Shankweiler, D. P. & Studdert-Kennedy, M. A continuum of lateralization for speech perception? Brain and Language, 1975, 2, 212-225.

Sperling, G. The information available in brief visual presentations. Psychological Monographs, 1960, 74, No. 11.

Sperry, R. W. Cortical specialization in the surgically separated hemispheres. In F. O. Schmitt & F. G. Worden (eds.) The Neurosciences: Third Study Program. Cambridge: MIT Press, 1974.

Studdert-Kennedy, M. Dichotic studies II: two questions. Brain and Language, 1975, 2, 123-129.

Studdert-Kennedy, M. & Shankweiler, R. D. Hemispheric specialization for speech perception. Journal of the Acoustic Society of America, 1970, 48, 579-584.

Teng, E. L. & Sperry, R. W. Interhemispheric interaction during simultaneous bilateral presentation of letters or digits in commissurotomized patients. Neuropsychologia, 1973, 11, 131-140.

Treub, S. E. & Rabinovitch, M. S. Auditory linguistic sensitivity in early infancy. Developmental Psychology, 1972, 6, 74-77.

Wallace, R. J. Stimulus-response compatibility and the idea of a response code. Journal of Experimental Psychology, 1971, 88, 354-360.

White, S. H. Evidence for a hierarchical arrangement of learning processes. In C. Ounsted & D. C. Taylor, Gender Differences: Their Ontogeny and Significance. London: Churchill Livingstone, 1965.

White, M. J. Visual hemifield differences in the perception of letter and contour orientation. Canadian Journal of Psychology, 1971, 25, 207-212.

White, M. J. Hemispheric asymmetries in tachistoscopic information-processing. British Journal of Psychology, 1972, 63, 497-508.

White, M. J. Does cerebral dominance offer a sufficient explanation for laterality differences in tachistoscopic recognition? Perceptual Motor Skills, 1973, 36, 479-485.

Whitty, C. W. M. & Newcombe, F. Disabilities associated with lesions in the posterior parietal region of the non-dominant hemisphere. Neuropsychologia, 1965, 3, 175-185.

Wilkins, A. & Stewart, A. The time course of lateral asymmetries in visual perception of letters. Journal of Experimental Psychology, 1974, 102, 905-908.

Witelson, S. F. & Pollie, W. Left hemispheric specialization for language in the newborn: neuroanatomical evidence for asymmetry. Brain, 1973, 96, 641-646.